

**Cognitive pathways in attitude formation
towards emerging technologies:
experimental evidence on media context and
individual factors**

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Abstract

This dissertation investigates how contextual factors and individual variables influence attitude formation toward emerging technologies through cognitive processes. Given that most people lack direct experience with emerging technologies such as gene editing and nanotechnology, media coverage becomes crucial in shaping public understanding and acceptance. Despite extensive research on different modes of communication between science and the public, it remains unclear how media coverage and audience characteristics jointly shape the formation of public attitudes toward emerging technologies. Building on persuasion theory, which highlights how attitudes are shaped through information processing, this research investigates how media contexts, including message framing, source characteristics, and visual presentation, interact with individual audience characteristics to influence attitude formation.

Three experimental studies in a news media context were conducted for this research. Study 1 ($N = 501$, UK, USA, Germany) examined eight technology issue blocks to assess the influence of individual and contextual factors. Following this, study 2 ($N = 314$, UK) tested the effects of message framing (gain/loss/neutral) and picture valence (positive/negative/none). Study 3 ($N = 649$, UK) manipulated source characteristics, including gender, age, and picture presence. All studies applied mixed research designs with multiple technology topics as within-subjects factors. Across all three studies, contextual factors such as message framing, visuals, or source attributes showed some influence on attitude formation, but these effects were moderated by individual-level characteristics. Individuals' prior attitudes, including subjective knowledge and subjective relevance perception, not only moderated the impact of media presentations on support and behavioral intentions toward emerging technologies, but also directly influenced perceptions of source credibility. These findings underscore the central role of pre-existing cognitive and motivational factors in attitude formation toward emerging technologies.

Zusammenfassung

In dieser Dissertation wird untersucht, wie kontextuelle Faktoren und individuelle Variablen die Einstellungsbildung gegenüber neuen Technologien durch kognitive Prozesse beeinflussen. Da die meisten Menschen keine direkten Erfahrungen mit neuen Technologien, wie beispielsweise Gentechnik oder Nanotechnologie, haben, ist die Medienberichterstattung entscheidend für die Bildung des öffentlichen Verständnisses und deren Akzeptanz. Trotz umfangreicher Forschung zu verschiedenen Kommunikationsmodi zwischen Wissenschaft und Öffentlichkeit ist nach wie vor unklar, wie Medienberichterstattung und Publikumseigenschaften gemeinsam die Entstehung von Einstellungen gegenüber neuen Technologien beeinflussen. Ausgehend von der Persuasionsforschung, welche die Rolle der Informationsverarbeitung bei der Entstehung von Einstellungen betont, untersucht diese Arbeit, wie Medienkontexte wie Framing, Quellenmerkmale und visuelle Gestaltung mit individuellen Publikumseigenschaften in Bezug auf die Einstellungsbildung interagieren.

Für diese Arbeit wurden drei experimentelle Studien im Nachrichtenmedienkontext durchgeführt. In Studie 1 ($N = 501$, Großbritannien, USA, Deutschland) wurden acht Technologiethemablöcke verwendet, um zunächst den Einfluss individueller und kontextueller Faktoren zu bewerten. Anschließend testete Studie 2 ($N = 314$, Großbritannien) die Wirkung von Medienframing (gain/loss/neutral) und Bildwirkung (positiv/negativ/ohne). Studie 3 ($N = 649$, Großbritannien) variierte Quellenmerkmale, darunter Geschlecht, Alter und Bildpräsenz. Alle Studien verwendeten gemischte Versuchsdesigns, bei denen mehrere Technologiethemata als Within-Subject-Faktoren einbezogen wurden. In allen drei Studien zeigten sich zwar Effekte kontextueller Faktoren wie Medienframing, visuelle Elemente oder Quellenmerkmale auf die Einstellungsbildung, diese wurden jedoch durch die individuellen Eigenschaften der Versuchspersonen beeinflusst. Die Voreinstellungen der Versuchspersonen, einschließlich subjektivem Wissen und wahrgenommener Relevanz des Themas, moderierten nicht nur den Einfluss der Medienpräsentation auf Unterstützung und Handlungsabsichten gegenüber neuen Technologien, sondern wirkten in einer Studie auch direkt auf die Wahrnehmung der Glaubwürdigkeit der Informationsquelle ein. Diese Ergebnisse unterstreichen die zentrale Rolle kognitiver und motivationaler Voreinstellungen bei der Bildung von Einstellungen gegenüber neuen Technologien.

Table of Contents

1. Introduction.....	1
1.1 Starting Point of this Research.....	4
1.2 Research Objectives	5
1.3 Structure of this Dissertation	10
2. Defining and Contextualizing Emerging Technologies.....	12
2.1 Definition and Typology of Emerging Technologies	12
2.2 Economic Implications	23
2.3 Sociological Context of Technology and Innovation	30
2.4 Policy and Regulatory Context	42
2.5 Science Communication Models and Perspectives.....	53
3. Theoretical Perspectives on Attitude Formation.....	82
3.1 Conceptualizing Attitude Formation	82
3.1.1 Defining Attitudes and Attitude Formation	83
3.1.2 Attitude as Determinant of Behavior	88
3.2 Theoretical Background of Persuasion Theory	95
3.2.1 Information Processing of Persuasive Communication.....	96
3.2.2 Overview on Influential Factors	112
3.2.3 Resistance to Persuasion and Counteracting Strategies.....	136
3.3 Attitude Formation in the Context of this Work	145
4. Literature Overview on Media Effects regarding Emerging Technologies.....	150
4.1 Agenda Setting and Media Framing.....	151
4.2 Media Effects.....	157
4.2.1 Individual Determinants	159
4.2.2 Media Framing Effects	168
4.2.3 Influence of the Source.....	178
4.3. Synthesis of Empirical Findings and Summary of Research Aims.....	187

5. Study 1: Influence of Contextual and Individual Determinants	197
5.1. Research Questions	197
5.2 Methods.....	205
5.2.1 Research Design	205
5.2.2 Experimental Manipulation	208
5.2.3 Procedure and Measures	209
5.2.4 Sample and Statistical Power	212
5.2.5 Data Analysis	216
5.3 Results.....	221
5.3.1 The Influence of Person-level, Topic-level, or Country-level differences.....	222
5.3.2 Overview on the Evaluation of the Technology Issues	222
5.3.3 Information Behavior as Determinant and the Influence of Country Background	229
5.4 Summary and Discussion	234
6. Study 2: Message Framing Effects	239
6.1 Research Questions and Hypotheses	239
6.2.1 Experimental Design.....	246
6.2.2 Experimental Manipulation	248
6.2.3 Procedure and Measures	252
6.2.4 Sample and Power Analysis	258
6.2.5 Data Analysis	259
6.3 Results.....	263
6.3.1 The Influence of Person-level and Topic-level differences.....	264
6.3.2 Message Framing and Message Congruency Effects.....	264
6.3.3 Moderators of Message Congruency Effects	272
6.4 Summary and Study Specific Discussion	277
7. Study 3: Source Credibility Effects	284
7.1 Research Questions and Hypotheses	284
7.2 Methods.....	291
7.2.1 Experimental Design.....	291
7.2.2 Experimental Manipulation	293

Table of Contents

7.2.3 Procedure and Measures	295
7.2.4 Sample and Power Analysis	301
7.2.5 Data Analysis	302
7.3. Results.....	306
7.3.1 The Influence of Person-Level and Topic-Level Differences.....	306
7.3.2 Source Cues of Gender, Age, and Picture of the Scientist	306
7.3.3 Moderating Influence of Prior Attitudes.....	314
7.4 Summary and Study Specific Discussion	316
8. Discussion and Conclusion.....	322
8.1 Summary	322
8.2 Theoretical and Methodological Limitations	329
8.3 Implications for Science Communication Research	339
8.4 Conclusion	342
References.....	347
Appendix: Literature Overview	436

Tables

Table 1. Science communication framework of the social conversation around science	81
Table 2. Overview of the seven postulates of the Elaboration Likelihood Model (ELM)	98
Table 3. Overview on effects of variables in persuasion studies.....	134
Table 4. Strategies and motivation for the resistance to persuasion.....	137
Table 5. Orientation–Stimulus–Orientation–Response (O–S–O–R) model.....	161
Table 6. Conditions of the counterbalanced 4x8 stimuli-within-block design for study 1	208
Table 7. Overview on the operationalization of measures and statistics for study 1 ...	212
Table 8. Sociodemographics of the sample for study 1 on the influence of contextual and individual determinants	216
Table 9. Results of the linear mixed-effect models predicting subjective knowledge, subjective personal relevance perception and subjective societal relevance perception concerning emerging technologies	233
Table 10. Example of the crossed data structure for the second study relating to message effects.....	248
Table 11. Overview on the operationalization of measures and statistics for study 2 .	256
Table 12. Sociodemographics of the sample for study 2 on message framing effects .	259
Table 13. Means and standard deviations of dependent variables for experimental conditions	265
Table 14. Bivariate correlations between technology conditions and support towards emerging technologies.....	267
Table 15. Bivariate correlations between technology conditions and behavioral intentions towards emerging technologies	267
Table 16. Results of the linear mixed-effect models predicting support and behavioral intentions towards emerging technologies	269
Table 17. Estimated contrasts comparing message congruency levels concerning support and behavioral intentions towards emerging technologies.....	272
Table 18. Bivariate correlations between moderator variables	273
Table 19. Example of the data structure for the third study relating to source effects .	293
Table 20. Overview on the operationalization of measures and statistics for study 3 .	299
Table 21. Sociodemographics of the sample for study 3.....	302

Tables

Table 22. Means and standard deviations of dependent variables for experimental conditions	307
Table 23. Bivariate correlations between technology conditions and message credibility	309
Table 24. Bivariate correlations between technology conditions and scientists' credibility	309
Table 25. Results of the linear mixed-effect models predicting message credibility and credibility of the scientist in newspaper articles on technology issues	313
Table 26. Bivariate correlations between moderator variables	314
Table 27. Summary of the empirical studies of this dissertation	324

Figures

Figure 1. Overview of factors to attitude formation toward emerging technologies	11
Figure 2. Overview of clusters of emerging technologies and technologies based on policy papers.....	23
Figure 3. Gartner Hype Cycle for emerging technologies.....	27
Figure 4. The diffusion of innovation and adopter categories.....	37
Figure 5. Elements and strategies of anticipatory governance of emerging technologies	52
Figure 6. Overview on periods and basic assumptions of science communication models and paradigms.....	57
Figure 7. Integrated model of Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB)	92
Figure 8. The Technology Acceptance Model (TAM).....	94
Figure 9. Elaboration Likelihood Model (ELM).....	102
Figure 10. The MODE model.....	107
Figure 11. Variables in the persuasion process	114
Figure 12. The Persuasion Knowledge Model	142
Figure 13. The issue-attention-cycle	154
Figure 14. Overview of recurring media frames in the context of emerging technologies	157
Figure 15. The Science Literacy and Heuristics Model (SLHM)	164
Figure 16. The affect model of risk	166
Figure 17. Integrated Model of Communication Influence on Beliefs (IMCIB).....	168
Figure 18. Overview on empirical studies and variables of this dissertation	196
Figure 19. Overview on determinants and outcomes regarding the research questions to the evaluation of emerging technologies for study 1.....	205
Figure 20. Stimulimaterial newspaper condition for study 1	209
Figure 21. Data analysis plan study 1 for the mixed effects data structure with stepwise inclusion of fixed effects	221
Figure 22. Mean scores of subjective knowledge of emerging technologies and technology groups	223
Figure 23. Mean scores of subjective personal relevance perception of emerging technologies and technology groups.....	224

Figure 24. Mean scores of subjective societal relevance perception of emerging technologies and technology groups.....	225
Figure 25. Mean scores of subjective knowledge of emerging technologies for technology groups and investigated countries.....	226
Figure 26. Mean scores of subjective personal relevance perception of emerging technologies for technology groups and investigated countries	228
Figure 27. Mean scores of subjective societal relevance perception of emerging technologies for technology groups and investigated countries	229
Figure 28. Overview on determinants and outcomes regarding the research questions and hypotheses for study 2	245
Figure 29. Stimulimaterial newspaper conditions for study 2.....	252
Figure 30. Data analysis plan study 2 for the mixed effects data structure with stepwise inclusion of fixed effects	263
Figure 31. Average marginal effects for text framing conditions and picture valence predicting support and behavioral intentions towards emerging technologies.....	270
Figure 32. Conditional average slopes for the interaction effects between message congruency and moderator variables in predicting support and behavioral intentions toward emerging technologies.....	277
Figure 33. Overview on determinants and outcomes regarding the research questions and hypotheses for study 3	291
Figure 34. Stimulimaterial newspaper condition for study 3	295
Figure 35. Data analysis plan study 3 for the mixed effects data structure with stepwise inclusion of fixed effects	305
Figure 36. Average marginal effects (AMEs) for conditions of scientists age and presence of a picture	312

1. Introduction

When faced with issues of high scientific importance, such as public health crises, communication strategies such as persuasion become a key tool to achieve desired outcomes quickly and effectively. Science communicators may enhance their ability to address pressing and urgent challenges by influencing public understanding, attitudes, and behaviors (Davies, 2022). In instances where individuals hold biased beliefs about scientific issues, science communication aims to provide accurate information and clarify misconceptions, for example, through direct rebuttals and corrective information for example, about the severity of a pandemic (Freiling & Matthes, 2023; Pennycook et al., 2020).

From the perspective of *science communication*, the manner in which scientific information is conveyed to the public or “the flow of information and risk evaluations back and forth between academic experts, regulatory practitioners, interest groups, and the general public (Leiss, 1996, p. 86)” is evaluated. In situations involving complex, uncertain, or controversial emerging technologies, these processes ultimately influence the societal understanding and acceptance of emerging technologies (Corbett & Durfee, 2004; Renn, 2015). However, it is imperative to recognize that the ongoing economic and scientific growth which underpins these developments ultimately relies on societal support, which can only be sustained if the public can comprehend and accept the role of these technologies in their lives (Miller, J., D., 2004; D. A. Scheufele, 2006).

In the absence of such acceptance, industry and political actors will encounter difficulties in implementing a path towards widespread adoption (D. A. Scheufele, 2013), for example, as evidenced by the resistance against genetically modified crops (Bauer, 1995; Gaskell et al., 1999). Concurrently, emerging technologies may carry inherent risks, such as the documented adverse effects of nanoparticles on human health and the environment (Dimitrijevic et al., 2015). In such cases, the dissemination of news media reports may yield so-called “boomerang effects,” resulting in the proliferation of polarized opinions and the adoption of motivated reasoning among recipients (Druckman & Bolsen, 2011; Hart & Nisbet, 2012). The public's limited awareness of scientific facts and technology debates has been associated with attitude formation, such as reduced support for technology (Ziman, 1991).

Within the realm of science communication, the employment of communication tactics is predicated on the application of common determinants of communication and persuasion models. These models comprise elements such as message content, message

style, the source of communication, the communication channel utilized, and the communication context. The effective shaping of attitudes towards science and technology is contingent upon the judicious integration of these variables (Besley & Dudo, 2022). As indicated in the existing literature, the questioning of the basic concept of scientific literacy, which is based solely on increasing factual knowledge, underlines the need for research to consider the broader social, cultural and media contexts in shaping public understanding and attitudes (Brossard & Nisbet, 2007; Laugksch, 2000).

With large investments in research and development in the United States and the European Union, the rapidly expanding domain of emerging technologies has tremendous economic and societal implications (Canton, 2004; National Science Board, 2018). Furthermore, the European Commission has underscored the economic significance of emerging technologies¹, such as biotechnology, nanotechnology, and artificial intelligence (AI), both in the near and medium future (European Commission, 2019). The impact of these emerging technologies is evident in terms of innovation, growth, and broader economic implications (Cozzens et al., 2010; Porter et al., 2002; Rotolo et al., 2015). Given a 15-year time horizon, these technologies are highly relevant in terms of economic influence (Porter et al., 2002).

Research on the emergence, development, and implementation of emerging technologies is substantial, frequently citing cyclical patterns of innovation (Corrocher et al., 2003; Rotolo et al., 2015). For instance, with respect to its economic implementation, as of 2024, Generative AI was expected to reach its plateau of visibility and business in 2 to 5 years, followed by declining recognition until adoption stabilizes (Chandrasekaran, 2024). Furthermore, the diffusion of innovations is crucial to understanding the societal dynamics surrounding emergent technologies. In this context, the roles of communication channels, social norms, and the characteristics of both adopters and technologies in influencing adoption rates have been identified as critical (E. M. Rogers, 2003). However, it has been contended that innovations are not universally beneficial and that their effects can vary across different contexts (E. M. Rogers, 2003). This underscores the notion that technologies are socially constructed, with their trajectories influenced by the priorities and interests of various stakeholders and cultural biases (Bijker, 1995).

¹ In the following, emerging technologies are concentrated on the typology of several emerging technologies proposed in policy papers (see chapter 2.1), encompassing the clusters of digital technologies, biotechnologies, energy and environmental technologies, and production technologies (OECD, 2016 and the European Commission, 2009, 2018c).

The role of policymakers is twofold; on the one hand, they influence economic growth, and on the other hand, they address societal challenges (Gokhberg et al., 2023; Ulnicane, 2022). However, governing emerging technologies is challenging due to factors including their rapid global diffusion (Guston, 2013; OECD, 2024a), sector convergence (Fabiani et al., 2024), and the resistance of strong interest groups (World Economic Forum, 2019). Furthermore, creator biases have the potential to influence societal impacts, as evidenced by the perpetuation of data-based biases through artificial intelligence (World Economic Forum, 2019). The uncertain nature of these technologies further complicates risk management and inclusive policymaking (Klinke & Renn, 2010; Renn, 2015). Given the transnational nature of emerging technologies, international cooperation is essential to coordinate global efforts, establish common regulatory frameworks, and develop common ethical standards (OECD, 2024a; World Economic Forum, 2019).

Policy documents in this area have underscored the necessity for governments to collaborate in the joint development of norms and technical standards. Illustrative of this approach are the endeavors of organizations such as the OECD, UNESCO, and the G7, which aim to ensure a harmonized approach to technology governance (OECD, 2024a). To avoid fragmentation in technology governance and ensure that no nation is left behind in addressing technological risks, the enhancement of multilateral dialogues and the establishment of universal standards have been proposed (OECD, 2024a). Recently, the approach of anticipatory governance has garnered attention as a means to address the unpredictable nature of technological progress. The objective of this approach is to guide innovation while minimizing risks and maximizing societal benefits. It involves strategic tools such as horizon scanning, technology assessment, and stakeholder engagement to anticipate future developments (OECD, 2024a). Despite the merits of these instruments, their use is often limited by uncertainty, abstract values and a technocratic approach that can sideline public concerns (Karinén & Guston, 2010; Nordmann, 2007).

Understanding the nuanced relationship between media coverage of emerging technologies and low public awareness requires a comprehensive understanding of how the public forms attitudes (D. A. Scheufele & Lewenstein, 2005). Historically, the public debate concerning emerging technologies has given rise to more critical media reporting, which has been focused on nuclear energy in the 1980s, biotechnology since the 1990s, and primarily on nanotechnology in the current century (Besley & Shanahan, 2005; Dudo et al., 2011; H. P. Peters, 1994). Moreover, an empirical examination of media reporting is critical for understanding public attitude, given the media's capacity both to promote

public understanding, acceptance, and to foster fear, skepticism, and the spread of misinformation (Anderson et al., 2014; D. A. Scheufele & Krause, 2019; D. A. Scheufele & Tewksbury, 2007).

1.1 Starting Point of this Research

Theoretical models and frameworks proposed in science communication research include one-way communication approaches, such as an emphasis on disseminating information for educational purposes or to improve the public's scientific literacy or public understanding of science (PUS) (Durant et al., 1989; Miller, J., D., 1983), which has been subsumed under the premise "the more you know, the more you love it" (Bauer et al., 2007, p. 83). Furthermore, two-way communication approaches gained importance which are related to dialogical concepts, such as public engagement approaches and participatory modes of communication, with the distinction of collaboration between scientific stakeholders and the public, which has been considered increasingly important in modern information environments (Bucchi & Trench, 2021; Trench, 2008).

In the case of emerging technologies such as artificial intelligence (AI), genetic engineering, and nanotechnology, effective communication has been associated not only with the provision of technical data and scientific information, but also with addressing the social, ethical, and psychological aspects that ultimately determine how beneficial or risky these technologies are perceived (Cutcliffe et al., 2012; Kahan et al., 2009; Kapoor & Klueter, 2021). Therefore, in order to understand the genesis of attitudes toward science and technology, it is essential to categorize the different modes of public perception of science in order to better identify effective modes of communication, address audience-specific needs, and evaluate relevant outcomes (Kessler et al., 2022; Lewenstein, 2003). It has been established that science communication models can be used as a context-specific analytical lens, thus also focusing on the process of media coverage of scientific issues in a way that makes them understandable and relatable to different audience members. Furthermore, this focus underscores the need for transparency and trust building to ensure that messages are effectively received by the public (Anderson et al., 2011; Árvai, 2014).

As posited by scholars in the field of social psychology, attitudes can be conceptualized as a tendency consisting of the evaluation of attitude objects (see for example Eagly & Chaiken, 1993; Fazio, 2007). It can be argued that media coverage can serve multiple functions, either to form new attitudes or to modify existing ones (Fazio, 1990;

Holbert & Tchernev, 2012). Attitude formation can be seen as an important outcome of the information process with regard to science news about emerging technologies. Support for this view is found in the deficit model (Miller, J., D., 1983), which posits that the public often begins with limited knowledge or awareness of complex scientific issues. Because people do not have strong, pre-existing opinions about these matters, their attitudes are strongly influenced by how science is presented to them, particularly through media coverage and the opinions of trusted sources such as scientists or business leaders (Cobb, 2005; Holbert & Tchernev, 2012; C. Lee et al., 2005).

Regarding the definition of the attitude construct, previous literature has suggested that it is not necessarily mandatory to distinguish between different processes such as attitude formation, attitude change, and attitude reinforcement because the underlying mechanisms of persuasion are applicable to all three concepts (Cameron, 2009; Petty & Wegener, 1998a). For example Petty and Wegener (1998a) used a continuum approach, from non-attitudes to strong attitudes, to reflect how attitudes vary in strength and accessibility. In consideration of the pivotal function of persuasion theory in the modeling of recipients' information processing, this dissertation aligns with the proposal for a continuum theory of attitude processes (see Petty & Wegener, 1998a), with the caveat that different attitude processes are not explicitly distinguished. In terms of terminology, the term "attitude formation" will be used throughout this dissertation. Consequently, the outcomes and determinants of attitude formation will be analyzed through the lens of several theoretical frameworks, including attitude-behavior approaches, persuasion frameworks and dual-process models, consistency theories, message-effect models, and applied cognitive processing models, with reference to science media use.

1.2 Research Objectives

The aim of this dissertation is to elucidate the attitude formation of news audiences towards emerging technologies by empirically testing the influence of news reporting context and individual variables. Considering the empirically only little supported variance of scientific knowledge on attitude formation towards scientific issues (Allum et al., 2008), research aimed to investigate how much influence additional audience-related factors have on attitudes towards emerging technologies (see for example Ho et al., 2008; D. A. Scheufele & Lewenstein, 2005). Therefore, it could be argued that existing science communication models and frameworks overlook the detailed mechanisms through which different cognitive biases and heuristics influence the reception of scientific

information in different contexts. As such, individual factors related to audience characteristics, such as sociodemographics, value predispositions, media use, and prior attitudes, were identified as influencing attitudes toward emerging technologies (Ho et al., 2010; D. A. Scheufele & Lewenstein, 2005). Consequently, the importance of interdisciplinary research in shaping the field of science communication has been emphasized, noting that insights from sociology, psychology, media studies, and other disciplines can contribute to a more nuanced understanding of how science is communicated and perceived (Bucchi & Trench, 2021).

By illustrating the interface of the media context, as shown in Figure 1, science policy decisions and how they are directed by economic conditions and societal impacts, the background of attitude formation towards emerging technologies is further elucidated. As evidenced by public surveys, general awareness of emerging technologies, for example with regard to nanotechnology or AI applications, can be considered low to moderate (European Commission, 2021c; Funk et al., 2023). However, the majority of respondents also show a general interest in technological developments, but have a low level of subjective knowledge about specific technologies such as nanotechnology (European Commission, 2010b). Public awareness and knowledge of science and technology is mainly influenced by the use of media, from which people receive information (Cacciatore, Anderson, et al., 2012; Nisbet et al., 2002). Thus, in the European Union, as assessed by the special Eurobarometer survey on science and technology in 2021, the main sources of public information on science and technology were television (63%), online social networks and blogs (29%), and online and printed newspapers (24%) (European Commission, 2021c).

As Figure 1 illustrates, the context in which media coverage occurs is expected to have a significant impact on attitudes toward emerging technologies. Several theories of media influence have been used to explain the process of attitude formation based on media coverage. The Agenda-setting Theory, introduced by McCombs and Shaw (1972), posits that the media do not tell people what to think, but rather what to think about (B. Cohen, 1963). Accordingly, the prominence and frequency of media coverage of a particular issue influences its perceived importance to the public (McCombs & Shaw, 1972). For example, consistent media coverage of artificial intelligence (AI) may lead the public to view it as an important issue, even if they do not fully understand its implications (Nguyen & Hekman, 2024). In addition, there is evidence of issue attention cycles (A. Downs, 1972) regarding nuclear energy (Gamson & Modigliani, 1989), and

biotechnology (Nisbet & Huges, 2006) showing that media interest rises and declines according to specific events or incidents, such as the Fukushima nuclear accident.

Media framing studies have shown that highlighting essential aspects of emerging technologies, such as economic competitiveness, public responsibility, or the scientific uncertainties or risks and benefits surrounding emerging technologies, influences audience attitudes, such as support or risk and benefit perceptions of these technologies and related applications (Donk et al., 2011; Marks et al., 2007). The framing of scientific information affects cognitive processes, as salience has been shown to increase the accessibility of certain frames (Tversky & Kahneman, 1973). Thus, framing at the individual level can be considered important in this regard, through which media frames influence cognitive aspects such as attitudes and behaviors (D. A. Scheufele, 1999). Framing effects reach their maximum potency when individuals and the accessibility of information engage in effortful reasoning, reinforcing the notion that perceived salience, as opposed to passive accessibility, serves as a primary driver of opinion formation (Chong & Druckman, 2007).

While research on the framing effects of textual elements of news coverage is extensive, less emphasis has been placed on visual framing effects (Geise & Baden, 2015). Nevertheless, as several authors have noted, the visual context of news reports that include pictures or photographs can be considered important in influencing audience cognitions and attitudes differently than text-based information (Borah, 2009; Messaris & Abraham, 2001). The isolated effect of pictures is expected to be superior for audience recognition compared to verbal messages in terms of increased applicability of visual elements (D. L. Nelson et al., 1976). Pictures in news reports were generally found to be influential as peripheral cues under conditions of low issue involvement (Petty et al., 1981; Petty et al., 1983). However, multimodal framing effects related to the combination of text and visual elements are mostly expected in a newspaper context, which has been studied, for example, in terms of cognitive responses such as the elaboration of risk information (Gibson & Zillmann, 2000; Trumbo, 1999). In this vein, it has been emphasized how the congruency between the message in the textual information and the visual presentation determines memory activation in both the verbal and visual memory subsystems (Powell et al., 2015; Seo & Dillard, 2019).

When scientists are portrayed as trustworthy and credible, the public is more likely to develop positive attitudes towards emerging technologies presented by these experts (Nisbet & Scheufele, 2009; Priest et al., 2003). Globally, and possibly as a result of

Covid-19, public trust in scientists, as indicated by the measure of trusting scientists "a lot", increased from 34% in 2018 to 43% by the end of 2020, as indicated by the Wellcome Global Monitor (Gallup, 2021). In this sense, the credibility of the source of communication, such as news outlets or scientists, has been considered essential, as individuals are more likely to be persuaded when the source credibility dimensions of expertise and trustworthiness are high (Hovland et al., 1953; Hovland & Weiss, 1951). Accordingly, the effectiveness of messages in altering attitudes depends on their perceived credibility (Chaiken et al., 1989; Petty & Cacioppo, 1986b). However, the source effect is influenced by the perception of personal relevance of individuals, for example, under low issue relevance, sources with high attributed expertise act as a peripheral cue to influence attitudes (Petty et al., 1981). Less research has investigated how credibility judgments are influenced by cues to source characteristics such as the status, gender, and age of a communicator. In this regard, studies have shown that attention before and after receiving a message can bias the processing of arguments and ultimately override the actual perceptual content of the message (Pearson, 1982; Weibel et al., 2008).

Science communication effects research appears to be a fragmented field, with a greater emphasis on survey research on public attitudes and less focus on experimental studies in this regard (Milde, 2017). However, it can be argued that by integrating the theoretical perspective of persuasion models, such as dual process approaches and science communication theories, the design and effectiveness of interventions can be improved by addressing how audiences perceive and process scientific information. Furthermore, from a news information processing perspective, cognitive elaboration can be expected to moderate or mediate the relationship between media exposure and attitudes toward scientific issues (Eveland & Cooper, 2013). This integrative perspective, which considers not only media effects but also how individuals cognitively process scientific messages, has been identified as a research gap in science communication research (Nisbet & Scheufele, 2009; Rimal & Real, 2003).

At the individual level, the variables shown in Figure 1, such as prior knowledge, and value predispositions that moderate attitudes toward technology, have played an important role in research (Nisbet, 2005). Reflecting the perspective of research on public attitudes towards science, this discussion can be argued to be divided between the scientific literacy perspective, which states that an increase in public knowledge of science is associated with an increase in public support, and the notion of a "miserly" public that relies on heuristic cues from mass media or as value predispositions to form attitudes (Ho

et al., 2008). The *cognitive response perspective* (Katz, 1960) suggested that the process of attitude formation is determined by the elaboration or degree of thinking about the attributes of an attitude object (Petty & Cacioppo, 1981, 1986a). This in turn influences the accessibility of the attitude and the strength of the attitude (Cameron, 2009; Petty & Wegener, 1998a). In the tradition of *dual-process models*, such as the Elaboration Likelihood Model (ELM), Heuristic-Systematic Model (HSM), and the MODE Model (Chaiken, 1980; Fazio, 1990; Petty & Cacioppo, 1986b), two information-processing pathways to attitude change have been proposed under conditions of low or high information-processing effort on the part of respondents. In persuasion research, several determinants of attitude formation have been discussed in terms of message factors, source factors, and individual variables (McGuire, 1985b).

To determine the extent to which contextual determinants of news coverage, including the issue context of emerging technologies, message framing, source credibility, and the visual presentation of content, are influential in comparison to audience-related individual factors such as sociodemographics, prior knowledge, issue relevance, and value predispositions, the following research question is posed for this dissertation:

RQ: Are contextual or individual factors related to media effects more important for attitude formation towards emerging technologies?

To address the research gaps raised, this dissertation will first outline attitude formation toward emerging technologies as a psychological construct. Using theoretical persuasion models, the central determinants of attitude formation will be examined, while media effects approaches will be integrated to consider the context of science news coverage. Furthermore, critical examination is warranted of individuals' cognitive reactions to media content regarding emerging technologies, which is shaped by information processing or elaboration and influenced by personal relevance perception, knowledge levels, value predispositions, and prior attitudes. To this end, three empirical studies were conducted, focusing on the aspects of contextual and individual determinants of attitude formation (study 1), message framing effects (study 2), and source credibility effects (study 3) concerning news reporting on emerging technologies.

1.3 Structure of this Dissertation

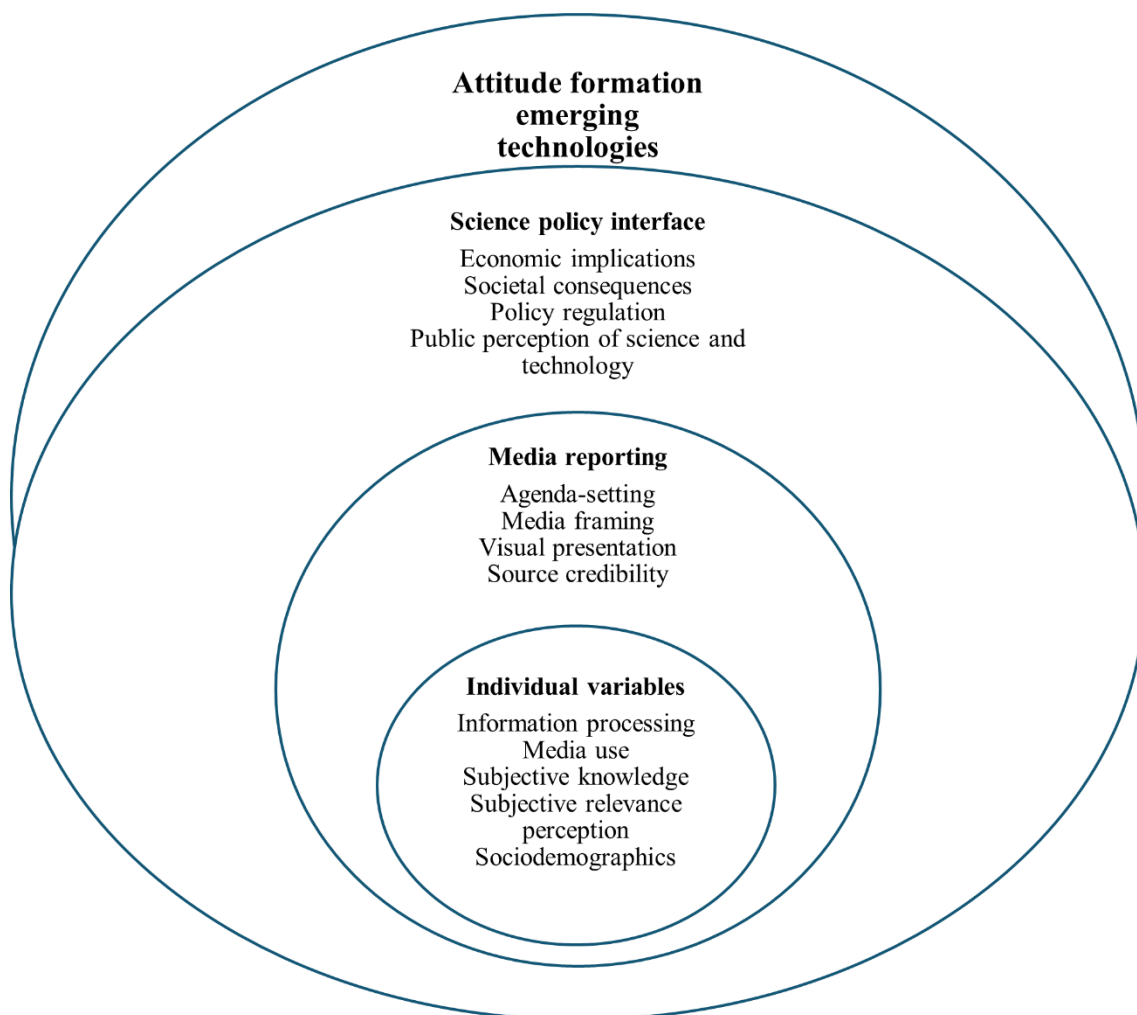
In order to review the societal and scientific context of emerging technologies, chapter 2 focuses on economic implications, the sociological background of science and technology perceptions, policy implications and models, and science communication models that have been used in the context of understanding public perceptions of science and technology. Chapter 3 will present an outlook on the central dependent variable of this research, which is the formation of attitudes towards emerging technologies. Drawing from the rich body of social psychology research, the construct of attitudes and the processes involved in their formation (chapter 3.1) will be defined and narrowed in chapter 3.1.1. Furthermore, the relationship between attitudes and behavior to be performed will be evaluated based on theoretical models (3.1.2). The perspective of persuasion theory and cognitive elaboration and information processing is then adopted (3.2), focusing on a comparison of persuasion models with a distinct focus on dual process models (3.2.1). Furthermore, the discussion in chapter 3.2.2 will center on the fundamental determinants of attitude formation, namely individual factors, message factors, and source factors. These determinants will be derived from persuasion theory and discussed based on exemplary experimental investigations in this tradition.

While attitudes are theorized to be shaped by persuasive efforts in specific circumstances related to the motivation and/or ability of recipients to process information, the possibility of resisting persuasive efforts should also be considered, which will be discussed in terms of the occurrence of resistance strategies and motivations and their preconditions (3.2.3). The present work's understanding of attitude formation is thus summarized in chapter 3.3, in relation to the various theoretical perspectives of psychology, science communication, and media effects research previously discussed. In order to evaluate the effects of media reporting regarding emerging technologies, chapter 4 will provide an integrative analysis of the extant empirical literature. It first examines the directions of media reporting regarding emerging technologies, including agenda setting and framing patterns (4.1), followed by an overview of media effects (4.2) regarding individual determinants (4.2.1), message framing effects (4.2.2), and source-based effects (4.2.3). Moreover, the implications of previous research and the objectives of the empirical investigations of this dissertation will be summarized in chapter 4.3.

To this end, the subsequent chapters will present the outlines and results of three experimental studies. These chapters on the empirical studies include the research aims, methods, results, and the discussion of the investigations related to individual and

contextual factors (chapter 5), message framing elements (chapter 6), and source-based characteristics (chapter 7) in science news reporting effects regarding emerging technologies. Finally, chapter 8 will provide a global discussion of the research findings, addressing the findings of the empirical studies (8.1) theoretical limitations of the research (8.2), drawing to implications for the field of science communication research (8.3) and concluding the research findings (8.4).

Figure 1. Overview of factors to attitude formation toward emerging technologies



2. Defining and Contextualizing Emerging Technologies

The potential of *emerging technologies* to drive innovation and create new opportunities across various sectors is a topic of frequent discussion (Day & Schoemaker, 2000). These technologies have been discussed to facilitate significant advancements in scientific and industrial domains, leading to the restructuring of existing markets and the emergence of entirely novel ones (Day & Schoemaker, 2000; European Commission, 2018c). Consequently, it is of great importance to gain an understanding of these emerging technologies, so that strategic decisions, research agendas and policy frameworks may be informed, guided and shaped, in such a way as to foster innovation, whilst addressing any potential risks (Rotolo et al., 2015). However, despite the societal importance of technologies, there is a lack of consensus on a unified definitional basis across different research fields, resulting in a fragmented conceptualization.

Chapter 2.1 will concentrate on defining emerging technologies by identifying their essential characteristics, including *policy regulations*, *societal environments*, and the *context-specific nature* of technological developments across different national settings and sectors. This includes an examination of the manner in which emerging technologies are grouped into clusters and the ways in which these clusters interact with the economic and scientific environments that support them. The conceptualization of "*emerging technologies*" requires an understanding of the ways in which these technologies are defined, categorized and discussed across different fields, including technology policy, innovation studies, and science communication. In this way, the chapter will facilitate a more nuanced comprehension of the interrelationships between these technologies and the broader economic (chapter 2.2) and societal systems (chapter 2.3), thereby informing policy decisions and strategic planning (chapter 2.4). Furthermore, the perspective of theoretical models and paradigms of science communication relevant to the context of emerging technologies will be outlined in chapter 2.5.

2.1 Definition and Typology of Emerging Technologies

Studies of media reporting patterns have demonstrated an association between emerging technologies and the subjects of nanotechnology and biotechnology (see, for example, Cacciatore, Anderson, et al., 2012; C. Lee et al., 2005). Moreover, regular public surveys are conducted on this matter (European Commission, 2010a). Nevertheless, there has been a lack of consensus on a clear and generally accepted definition or conceptualization of emerging technologies (H. König et al., 2021; Litvinski, 2018; Rotolo et al., 2015). E.

M. Rogers (2003) contends that, in a functional sense, *technology* can be defined as comprising two constituent components. Firstly, there is the hardware aspect, which is constituted by the tool that embodies the technology as material or physical objects. Secondly, there is the software aspect, which is constituted by the information base for the tool (p.12). Literature on the subject has discussed technology in terms of its technical origin and processes, market determinants of technological innovation, and technical diffusion in society (Arthur, 2009; E. M. Rogers, 2003; N. Rosenberg, 1972). Technology in general encompasses tools, systems, and knowledge at any stage of maturity, including both well-established technologies and new developments, focusing broadly on their practical applications and utility (E. M. Rogers, 2003; N. Rosenberg, 1972).

In contrast, *emerging technologies* are distinguished by a number of factors that underscore their transformative potential for industry and markets (see for example Cozzens et al., 2010). These technologies are innovative and possess a great deal of potential for future development. Furthermore, it must be acknowledged that these technologies are in their initial stages of development and necessitate substantial foresight and governance to ensure their optimal functioning and safety (Cozzens et al., 2010; Day & Schoemaker, 2000; Porter et al., 2002). Some conceptualizations of emerging technologies also relate to the scientific base of technology, emphasizing its origin in scientific advances (Cozzens et al., 2010; Day & Schoemaker, 2000). Nevertheless, there is no consensus among scholars that scientific breakthroughs are invariably accompanied by technological innovations. For instance, certain developments, such as smartphones, represent evolutionary progress rather than radical scientific breakthroughs, integrating existing technologies into novel interfaces (Rotolo et al., 2015).

The term "*key enabling technologies*" (KETs), which is often employed in policy contexts, differs from the broader conceptualization of emerging technologies (European Commission, 2009, 2019). KETs are associated with technologies that have demonstrated potential to drive innovation and economic growth across multiple sectors (Tallat et al., 2024). Conversely, an understanding of key enabling technologies encompasses specific technologies and applications, including nanotechnology, microelectronics, and advanced manufacturing technologies (European Commission, 2009). Emerging technologies, on the other hand, are broader in scope and include advanced technologies that are still in *the early stages of development*. They have the potential to significantly influence global economic and technological landscapes, as well as societal structures (OECD, 2016; Rotolo et al., 2015). Unlike KETs, emerging technologies are defined not only by

their applicability in specific domains but also by their transformative and cross-cutting nature for society (Porter et al., 2002; Rotolo et al., 2015), making them particularly relevant for science communication (D. A. Scheufele, 2013). As Brossard and Nisbet (2007) have observed, these technologies commonly encompass pioneering research, possess the potential to influence a wide array of daily living and scientific investigation contexts, and illustrate the efficacy of influencing public discourse and fostering comprehension of the societal repercussions that accompany technological advancements.

In conclusion, it should be noted that the basic concept of “*technology*” encompasses tools and systems at various stages of maturity, while the term “*key enabling technologies*” is used to highlight particular, well-established drivers of innovation in policy contexts. *Emerging technologies*, by contrast, are distinguished by their innovative potential, their status as being in the early stages of development, and their broad applicability (Porter et al., 2002). These distinctions render emerging technologies an essential focus for understanding the interplay between technological development, governance, and societal impact (Rotolo et al., 2015). A review of literature pertaining to emerging technologies reveals a broad spectrum of conceptualizations that are mainly applicable to comprehending innovation and technological progress (Cozzens et al., 2010; Rotolo et al., 2015). The definition of emerging technologies proposed by Rotolo et al. (2015) captures the nuanced and multidimensional nature of these innovations:

“We conceive of an emerging technology as a *radically novel* and *relatively fast-growing* technology characterized by a certain degree of *coherence* persisting over time and with the potential to exert a considerable impact on the *socio-economic domain(s)*, which is observed in terms of the composition of actors, institutions, and patterns of interactions among them, along with the associated knowledge production processes” (p.1832-1833).

This definition highlights two key points. Firstly, it emphasizes the capacity of emerging technologies to transform the economy and society. Secondly, it underscores the necessity of careful consideration when analyzing the introduction and dissemination of these technologies (D. A. Scheufele & Lewenstein, 2005). The societal impact of emerging technologies, particularly during their emergence phase, remains “somewhat *uncertain* and *ambiguous*,” necessitating a thoughtful approach to regulation and management to maximize benefits while mitigating potential disruptions (Rotolo et al., 2015, p.1832-1833).

As is evident in the extant literature, emerging technologies have been the focus of numerous scientific discourses, with a particular emphasis on their essential aspects and dimensions. A variety of methods for identifying emerging technologies have been outlined in the existing literature. In the context of *technological forecasting* within the domain of public policy, potential technological impacts are anticipated for emerging technologies at an early stage, or alternatively, to predict their future developments (OECD, 2016). To predict a technological impact, a combination of qualitative and quantitative approaches is typically employed. Qualitative methods include expert assessments (Calleja-Sanz et al., 2020; Favaro et al., 2022), moreover quantitative methods are for example based on text mining, which may utilize data from databases or patent records (Chiarello et al., 2021; Moro et al., 2018). Furthermore, scientometric methodologies, such as co-citation analysis, have been utilized to examine the stance of research within the domain of emerging technologies (Abercrombie et al., 2012; Glänzel & Thijs, 2012). Rotolo et al. (2015) observed a notable increase in the prominence of publications utilizing the term "emerging technologies" from 1980 to 2013, as evidenced by the SCOPUS database. This growth exhibited an average yearly expansion rate of 12.5% across all disciplines and 23.8% within the social sciences, in comparison to an average yearly growth rate of 4.9% for all publications in SCOPUS.

Overview on key emerging technologies in the policy context

In the empirical literature on emerging technologies, a number of dimensions are typically considered. These dimensions facilitate comprehension of the complex nature of emerging technologies and are applicable to policymaking, the dimension of development and research, and their economic implementation. For example, Cozzens et al. (2010) provide a conceptual overview of the term "emerging technologies" as recorded in the Web of Science, analyzing different aspects of the literature on emerging technologies since 1960. They identify two key dimensions: a *time-related dimension*, which refers to current technologies and technological development and change, and a *strategy-related dimension*, which highlights technological innovation, technology adoption, and technology diffusion, particularly in the context of disruptive technology. Additionally, emerging technologies were delineated in accordance with their specific type or role, as defined by their technical features, such as whether they are complementary or applied technologies. Moreover, the authors identified a *sectoral dimension*, which pertains to specific technology sectors, such as information technology and biotechnology. The authors also

highlighted the role of technology forecasting, foresight, and economic development across various disciplines (see Cozzens et al., 2010).

Policy decisions such as the European Union's Horizon 2020 framework program (European Commission, 2018b; European Parliament, 2021) are especially essential in defining key emerging technologies (also mentioned as “Future Emerging Technologies”, or *FET*) (NARD, n.d.). It is also imperative to consider their consequences for societal challenges, including health, demographic change, food security, sustainability, clean energy, green transport, climate action, and inclusive and secure societies (OECD, 2016). As part of the Horizon 2020 initiative, a comprehensive examination of Leadership in Enabling and Industrial Technologies (LEIT) in a variety of technological domains has been conducted, including its implications for nanotechnologies, advanced manufacturing, and biotechnology (European Commission, 2020b, 2021b).

The structure of policy papers often revolves around *technology clusters*², which consist of “one or more distinguishable elements of technology that are perceived as being closely interrelated” (E. M. Rogers, 2003, p. 14). These clusters serve as actionable frameworks, aiming to propel key technological domains and foster technological leadership. Primarily, these initiatives aim to ensure the sustained competitiveness of critical sectors (European Commission, 2021b). Therefore, a critical component of policy implementation involves the identification and prioritization of key emerging technologies, as evidenced by policy reports from the European Commission (2009, 2018c). A framework developed by the European Commission (2009) compiles key enabling technologies with the highest strategic relevance based on three criteria, their *economic potential*, their contribution to the resolution of *societal challenges*, and their *knowledge intensity*. According to these criteria, the European Commission (2009) has identified six key enabling technologies (KETs) deemed relevant in terms of both economic and societal impact, including advanced manufacturing technologies, advanced materials, nanotechnology, micro-/nano-electronics, industrial biotechnology, and photonics. In a 2018 outlook, the European Commission regrouped emerging technologies into the three main categories of production technologies, digital technologies, and cyber technologies. The advent of Industry

² Technology clusters have been the focus of research in the context of this work, as they play a pivotal role in driving innovation and advancements within specific technology areas. This focus enables the analysis of how expertise and resources in these clusters support technological growth. In addition, regional clusters are of particular relevance in policy contexts, as they underscore broader economic dynamics and the integration of advanced technologies into diverse industries, thereby offering a comprehensive perspective on development (European Commission, 2021b).

4.0 has served as a paradigm for the profound and revolutionary impact of emerging technologies, such as 3D printing, the Internet of Things (IoT), advanced robotics, bio-/nano-based materials, data-driven production, artificial intelligence (AI), and synthetic biology, on industrial production (European Commission, 2018c).

A more comprehensive typology of key emerging technologies has been presented by the OECD in their Science, Technology and Innovation Outlook (2016). In national foresight exercises conducted by several OECD countries, including Canada, Finland, Germany, the United Kingdom, and the Russian Federation, the objective was to identify promising emerging technologies over a 10 to 20 years horizon. To predict key future technological developments, national strengths and needs were analyzed. While the six exercises identified over 100 key technologies, there was an overlap in results reflecting common global trends and challenges. The final categorization described 40 key emerging technologies across several sectors, including *digital technologies*, *biotechnologies*, *advanced materials*, and *energy technologies*. These areas of emerging technology were highlighted for their significant innovation potential and impact on various fields. However, this report did not aim to prioritize the selected technologies. Instead, the objective was to provide a comprehensive overview of the potential for technological change to disrupt various sectors (OECD, 2016).

As illustrated in Figure 2, four technology clusters were identified for this dissertation based on the policy papers previously discussed. The broad technology clusters presented herein were derived from the OECD Science, Technology and Innovation Outlook³ (2016), which explicitly referred to emerging technologies as a subject to be relevant over a 10–20-year horizon. This definition aligns with the conceptualization of emerging technologies outlined in this chapter, emphasizing coherence over time and their transformative and cross-cutting nature for society (Rotolo et al., 2015). A comprehensive review of the selected policy papers (European Commission, 2009, 2018c; OECD, 2016) has yielded the identification of four technology clusters comprising 32 emerging technologies.

³ However, the technology cluster of advanced materials was encompassed in the typology under the term production technologies, as the European Commission (2018c) has suggested. This was done to reflect the broader applicability of advanced materials, such as smart materials, and of technology areas applied in the production process, especially nanotechnology.

1. Digital technologies

Digital technologies have been identified as a primary catalyst for societal transformation, exerting a profound influence on the landscape of employment and infrastructure (OECD, 2016). Additionally, the widespread adoption of digital technologies assumed greater significance during the pandemic for industrial sectors (European Commission, 2021b). European funding programs, such as the Digital Europe Programme (DIGITAL), prioritized the extensive utilization of these technologies in industry, small and medium-sized enterprises (SMEs), and public administration settings (European Commission, 2024e). Another notable initiative is "Digital Compass," which emphasizes digital competencies, the digital transformation of enterprises, and the development of digital infrastructures (European Commission, 2021a). Moreover, the European Commission has underscored the capabilities of information and communication technologies (ICT) in this regard, highlighting advancements in electronics, microsystems, data processing, robotics, and networking (European Commission, 2020a, 2020b).

A cursory review of the extant policy papers revealed that the cluster of digital technologies for this work includes the eight distinctive technologies of the Internet of Things (IOT), Artificial Intelligence (AI), robotics, cloud computing, photonics, big data, grid computing, and blockchain. Of particular note is the utilization and application of artificial intelligence (AI), which can be regarded as a highly relevant umbrella area. The development and advancement of AI is associated with a multitude of service industries, including entertainment, medicine, marketing, and finance (OECD, 2016, 2024b). A substantial body of policy recommendations and reports has been dedicated to this subject, with AI being defined as referring to “systems that display intelligent behavior by analyzing their environment and taking actions – with some degree of autonomy – to achieve specific goals” (European Commission, 2018a, p. 1). Recent initiatives have placed a stronger emphasis on the regulatory and ethical considerations of AI, underscoring the imperative that AI development should be consistent with national values and legal regulations. For instance, the AI Act has been established as the EU's inaugural legal framework for AI, with the objective of addressing potential risks of AI, promoting trustworthy AI to ensure safety and fundamental rights, and supporting innovation (European Commission, 2024b).

2. Biotechnologies

The second technology cluster of interest were *biotechnologies*, encompassing the technologies of personalized medicine, stem-cell therapy, medical imaging, regenerative medicine, remote patient monitoring (RPM), neurotechnology, biosensor, and synthetic biology. As a research field, biotechnology “applies science and technology to living organisms, as well as parts, products and models of them, to alter living or non-living materials to produce knowledge, goods and services” (European Commission, 2024d). The scope of biotechnology is extensive, encompassing diverse fields such as healthcare, pharmaceuticals, agriculture, marine and aquaculture, and industrial processes (European Commission, 2024d). Since as far back as 1990, the European Commission has maintained an independent advisory group on the implications of biotechnology to evaluate the innovative potential of biotechnologies, addressing ethical, regulatory, and public concerns (European Commission, 2002).

Ethical concerns surrounding biotechnologies, including stem-cell therapy, neurotechnology, and synthetic biology, have given rise to profound inquiries regarding the extent to which science should manipulate human biology and life (European Commission, 2022). Synthetic biology is an emerging field with a variety of techniques, including genome editing. One such approach is Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), and especially CRISPR-Cas9, known as “genetic scissors,” is a precise and efficient genome-editing tool discovered in 2012, allowing targeted DNA modifications (European Parliament, 2022). Another salient area of research in the field of synthetic biology is do-it-yourself (DIY) biology, or “biohacking,” defined as the work of an expanding community of individuals and small organizations engaged in the “study and practice of biology and life sciences outside the traditional professional context” (OECD, 2016, pp. 105–106). Moreover, personalized medicine, medical imaging, regenerative medicine, biosensor technology, and remote patient monitoring (RPM) share a focus on advancing healthcare through innovation and improving patient outcomes by leveraging cutting-edge technologies (DIGITALEUROPE, 2024; OECD, 2016). These technologies have been argued to emphasize individualized treatment, data-driven decision-making, and enhanced patient care (World Health Organization, 2021).

3. Energy and environmental technologies

According to the OECD (2016), the global primary energy demand is projected to increase by 37% between 2012 and 2040. This growth trajectory positions *energy and*

environmental technologies under the fourth most crucial technology domain over the next 15 years (OECD, 2016), thus representing the third technology cluster (see Figure 2). The relevance of promoting energy technologies was underlined by the European Strategic Energy Technology Plan (SET Plan), established in 2007 to foster the transition towards a climate-neutral energy system through the development of low-carbon technologies, underscoring the importance of promoting energy technologies (European Commission, 2015). Action areas in the category of energy and environmental technologies prioritize advancing sustainable and secure energy systems through innovation and efficiency. Key efforts for achieving these goals include integrating and reducing costs of renewables, enhancing energy system resilience, developing consumer-focused technologies, and encompassing advanced energy storage technologies. These technologies include advanced energy storage technologies, with a particular focus on renewable sources such as solar and wind energy, as well as the development of smart grids and fuel cell technology for the production and safe storage of hydrogen (Eulaerts et al., 2024; European Commission, 2015).

Furthermore, electric vehicles are included in this category of technologies, with an emphasis on control systems that enhance the environmental neutrality and energy efficiency of vehicles (Eulaerts et al., 2024; OECD, 2016). Additionally, the potential of Unmanned aerial vehicle (UAV), also referred to as “drones”, for optimizing irrigation or fertilization in agriculture, or supporting the infrastructure maintenance and inspections, has been evaluated (European Commission, n.d.–b). The potential of innovative AI-based technologies in the domain of agricultural technologies and methods to enhance land productivity in a sustainable manner has emerged, with precision agriculture (PA) (also known as “precision farming”) being a key area of interest (European Commission, 2024c). Examples of PA include remote sensing platforms, which are used to monitor crop conditions, and in-ground sensors, which provide real-time data on soil moisture and nutrients (GAO, 2024).

4. Production technologies

As displayed in Figure 2, the cluster of *production technologies* encompassed a range of *advanced materials* that can be utilized in the manufacturing process, including functionally graded materials (FGMs), lightweighting, smart materials, two-dimensional (2D) materials, 3D printing, and high-performance plastics (European Commission, 2018c). Advanced materials have been identified as playing a pivotal role in facilitating the EU's

green and digital transitions. Their distinctive characteristics foster innovation in domains such as energy, mobility, and electronics. These materials can substitute critical raw materials, reduce reliance on fossil fuels, and promote circularity (European Commission, 2024a). The application of *nanotechnology* in the manufacturing processes⁴ as nanomaterial, which is based on the control of matter at the atomic scale and either natural, incidental or artificially manufactured/engineered (OECD, 2016), has been discussed in the context of potential improvements in productivity.

According to the European Commission (2004), “*nanotechnologies*” refer to technological fields concerning the controlled manufacturing of functional nanosystems or the deliberate creation of nanostructures⁵ that results in the production of entities with at least one dimension on the order of the 100 nm length scale of nanoparticles⁶ (p.17). The production processes involving nanoparticles include nanotextured surfaces, engineered nanotubes, engineered nanoparticles, and engineered nanomachines (European Commission, 2004). However, the orientations of nanosciences can be discriminated between the different kinds of nanotechnologies, for example medical applications, information technologies, food, energy production and storage, security, materials science, and manufacturing (European Commission, 2004), which has led to the justification of significant investments in a range of sectors (European Commission, 2009).

A series of key recommendations have been put forth for the consideration of nanotechnologies in policy reports. These recommendations include the conducting of life cycle assessments, the study of health and environmental risks, the avoidance of nanoparticle release, the updating of regulations, and the ensuring of workplace and consumer safety. In addition, there has been a strong emphasis on the necessity of incorporating ethical and social implications into research and training to promote public dialogue (The Royal Society and Royal Academy of Engineering, 2004). However, it has also been noted that an incremental process involving existing legislative frameworks,

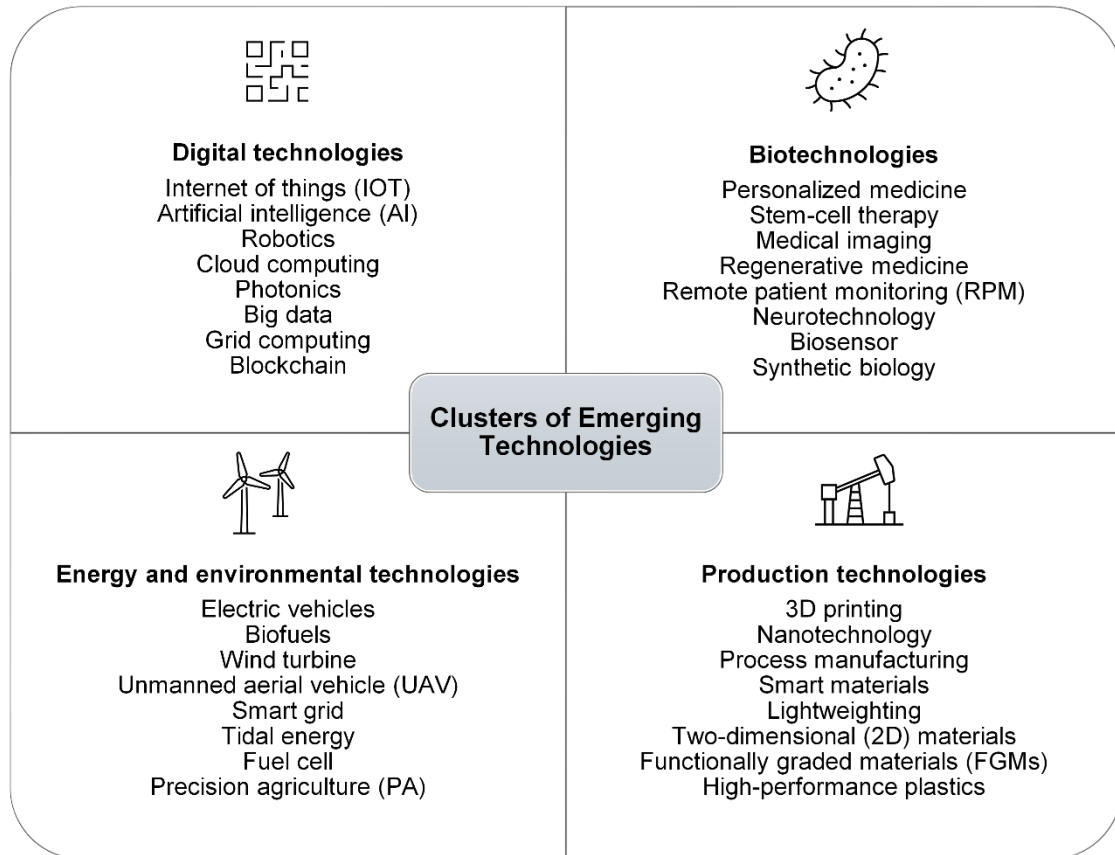
⁴ Advanced manufacturing is distinguished by the implementation of specific families of advanced IT-based production technologies. These technologies are frequently associated with other advanced technologies, including biotechnologies. A recent study identified 15 technology areas that correspond to “distinct clusters of advanced digital technologies and solutions that can be deployed to enable and enhance manufacturing processes” (Fabiani et al., 2024, p. 55).

⁵ By definition “nanostructured materials” are “constructed atom by atom or molecule by molecule” (European Commission, 2004, p. 18).

⁶ “Nanoparticles” can be defined as elements with dimensions less than 1 micrometer (< 0.000001 m), designed and manufactured nanoparticles tend to have dimensions less than 100 nanometers (< 0.0000001 nm) (European Commission, 2004, p. 17).

such as regulations on dangerous substances, classification and labeling, should be utilized as a foundation for addressing emerging issues like nanomaterials (European Commission, 2004). Significant legislative developments within the European Union, such as the European Food Safety Authority (EFSA) amendment in 2002, which introduced provisions for the safety assessment of food containing or consisting of nanomaterials (efsa, 2025; European Commission, n.d.–a), and the REACH chemical legislation founded in 2018 to enhance the registration, evaluation, and authorization of chemicals (The Royal Society and Royal Academy of Engineering, 2004), underscore the EU's proactive stance on this matter. Nevertheless, a review of the subject reveals certain regulatory gaps within European policy recommendations. These gaps pertain to the need for clearer definitions, more comprehensive risk assessments, and more effective enforcement and implementation of nanomaterial regulations (Nielsen et al., 2023). In order to provide a comprehensive and precise description of the key areas of implications concerning emerging technologies, the research object of emerging technologies will be analyzed and narrowed in the next step.

Figure 2. Overview of clusters of emerging technologies and technologies based on policy papers



Clusters of emerging technologies and subsequent emerging technologies were derived from the OECD Science, Technology and Innovation Outlook 2016 (OECD, 2016), as well as policy papers by the European Commission (2009, 2018c).

2.2 Economic Implications

The economic potential of emerging technologies has been widely explored as key dimension in the empirical literature, with a focus on innovation, growth, and broader economic implications (Cozzens et al., 2010; Porter et al., 2002; Rotolo et al., 2015).

Innovative potential of emerging technologies

In concluding the systematic studies on the dimensions of emerging technologies, one of the most widely discussed dimensions is the *innovative* or *novelty potential* of these technologies. This dimension captures the ability of a technology to introduce new ideas, methods, or applications, distinguishing it from pre-existing technologies. Novelty plays a central role in advancing innovation, as it fosters the development of unique solutions

to address unmet needs or improve efficiency (e.g., Porter et al., 2002; Rotolo et al., 2015). As some authors have indicated, the dimension of novelty bears a strong relationship to the advancement of innovation (C. M. Christensen et al., 2018; Small et al., 2014). The concept of "*innovation*" encompasses the complexity of technology and influences the diffusion of innovations (E. M. Rogers, 2003). In the domains of science, technology and innovation ("ST&I") analysis and management studies, it has been proposed that the designation of "emerging technologies" exhibits some overlap with the notion of "*disruptive technology*". The term "disruptive technology" (DT) is used to describe a technology that has the potential to alter the competitive landscape by influencing performance measures (Bower & Christensen, 1995). However, the concept was later extended to "*disruptive innovation*" (DI) to encompass broader disruptions beyond technology, as proposed by Schumpeter (1976) and subsequently developed by C. Christensen and Raynor (2013).

The term "innovation" itself can be defined as "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)" (OECD/Eurostat, 2018, p. 20). Consequently, innovation is not solely limited to technological product innovations that alter the firm's products; it also encompasses business process innovations that transform the firm's underlying business processes. Collectively, these two components can be defined as technological product and process innovation (TPP) (OECD/Eurostat, 2018). In general, TPP innovations comprise a variety of scientific, technological, organizational, financial, and commercial activities (OECD/Eurostat, 1997). Innovations are typically classified as either incremental or radical (Acemoglu et al., 2022; Coccia, 2017). Incremental innovations are defined as small improvements resulting from continuous processes or industries, such as "learning by doing," which cause relatively little disruption and can be predicted. In contrast, radical innovations, or "technological discontinuities," involve the emergence of entirely new technologies that displace incumbent technologies. For example, electric vehicles have replaced gas-fueled vehicles, and flash drives have replaced diskettes and compact disks (Cozzens et al., 2010; Day & Schoemaker, 2000).

Furthermore, industries differentiate between sustaining innovations (enhancing mainstream performance) and disruptive innovations (targeting overlooked segments). This distinction shapes competitive dynamics, favoring new entrants over incumbents. In this context, disruptive technology has a retrospective nature, where the disruption has

already occurred (M. Li et al., 2018). Nevertheless, it has been observed that the differentiation between disruptive technology and disruptive innovation remains ambiguous, with overlapping definitions and ongoing theoretical debates (M. Li et al., 2018; Yu & Hang, 2010). The concept of emerging technologies, as opposed to disruptive technologies and disruptive innovation, is more often employed in operational terms in interdisciplinary contexts such as public policy and communication. Consequently, research on emerging technologies describing potential socio-economic impacts has a strong focus on the social aspects of these technologies in the context of public attitudes, such as the perceived risks of nanotechnology (M. Li et al., 2018).

Growth and adoption trajectories

Furthermore, another dimension of innovation that is frequently discussed in the literature is *growth*, which is often defined in terms of the speed and scale at which a technology progresses from its initial development to widespread adoption. Porter et al. (2002) defined more specifically for emerging technologies that they will "exert much enhanced economic influence in the coming (roughly) 15-year horizon." (p.189). Rotolo et al. (2015) further proposed that growth be assessed through the lens of "relatively fast growth," often measured by indicators such as patent filings, publication trends, or market performance. For instance, technologies that demonstrate accelerated "patent activity above the average for their domain" are likely to achieve faster adoption and integration into industries (Corrocher et al., 2003, p. 17).

Within the *emergence framework*, a long-term perspective is offered on the progression of technologies from initial concepts to their integration within industrial and societal domains. Accordingly, three phases of development were identified (see Rotolo et al., 2015). The initial phase is the *pre-emergence phase*, during which the technology is still in its preliminary stages of development and is primarily researched within academic institutions. During this phase, the knowledge base surrounding the technology is limited, and there is considerable uncertainty regarding its potential applications. Moreover, there are few commercial applications, and the technology is largely unrecognized outside of specialized academic or research fields (Rotolo et al., 2015). The second phase is the *emergence phase*, during which the technology begins to gain visibility and recognition. Significant advancements in the field attract the attention of a diverse range of stakeholders, including industry leaders, policymakers, and the general public (Rotolo et al., 2015). The initial commercial applications of the technology begin to emerge,

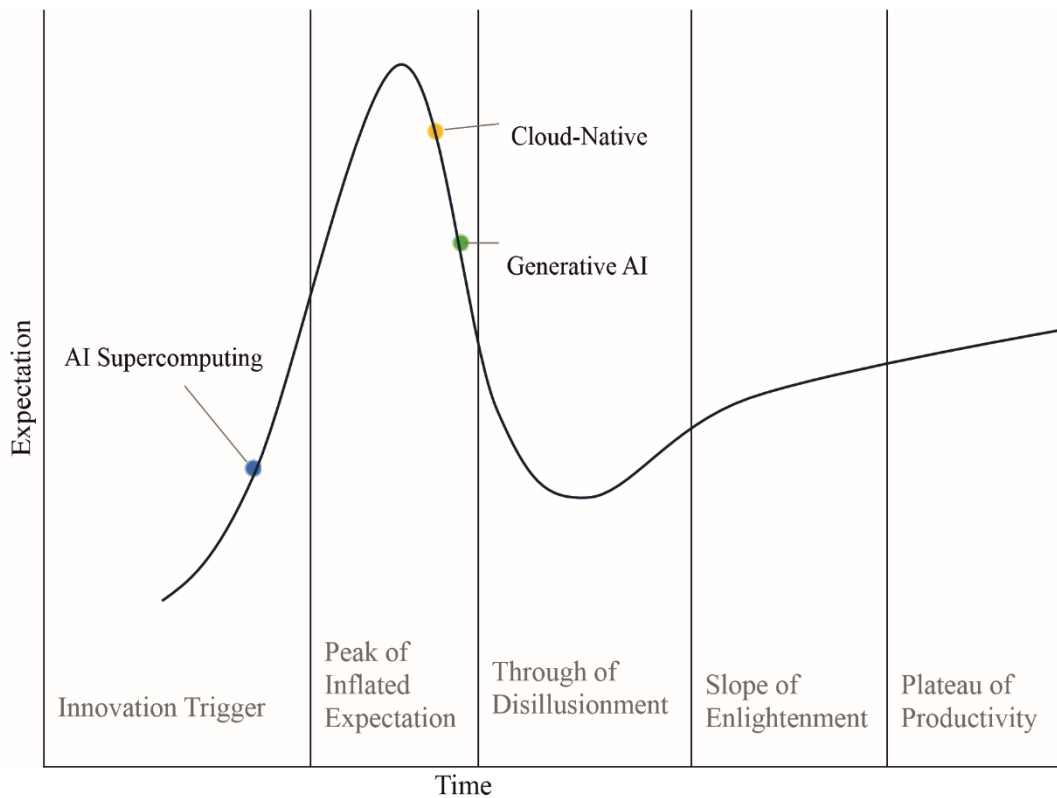
accompanied by an increase in investment as its potential becomes more apparent and widely acknowledged. In the third phase, the *post-emergence phase*, the technology is widely adopted and integrated into industries. Technology's impact on markets and society becomes significant, and the focus shifts from initial development to optimization and scaling. In this phase, the challenges of competition and regulation become more prominent, necessitating the development of strategies to address these emerging complexities. It should be noted, however, that these phases represent general trends rather than fixed stages (Rotolo et al., 2015).

While the emergence framework examines the broader trend of the development and implementation of emerging technologies, the *Gartner Hype Cycle* (Chandrasekaran, 2024) focuses on the visibility, maturity, and business adoption of these technologies. As shown in Figure 3, the cycle maps the journey of innovations through five distinct stages, beginning with the *innovation trigger*, where a breakthrough or new concept sparks excitement but has yet to demonstrate commercial viability. As part of the technology group of autonomous AI, AI supercomputing (computational resources required to train advanced AI models) experienced this stage in 2024 with the expectation to reach its plateau in 2 up to 5 years (Chandrasekaran, 2024). This stage is followed by the *period of inflated expectations*, where initial successes and ambitious claims generate widespread enthusiasm, leading to unrealistic expectations as stakeholders anticipate immediate, transformative impacts. For example, Generative AI was in this phase (see Figure 3), with promises of revolutionizing industries such as healthcare, transportation, and finance dominating public discourse, even as unresolved challenges like bias in decision-making and ethical concerns persist. As of 2024, Generative AI was expected to reach its plateau in 2 up to 5 years (Khandabattu, 2024).

In the context of improving developer productivity, cloud-native technologies in 2024 were on the peak within the next 5 to 10 years (see Figure 3) to enable organizations to build and run scalable applications for cloud environments (Chandrasekaran, 2024). Next, as interest wanes and many early adopters experience setbacks, comes the *trough of disillusionment*. Technologies often fail to meet inflated expectations during this phase, leading to skepticism and abandonment by some organizations (Gartner, n.d.). Generative AI could enter this stage if surviving vendors' investments in this area improve their products to the satisfaction of early adopters (Gartner, n.d.). This is followed by the *slope of enlightenment*, where stakeholders gain a clearer understanding of the technology's capabilities and limitations, leading to improved strategies and incremental improvements.

For Generative AI, this could include refining applications where the value of the technology becomes more apparent (Gartner, n.d.). Finally, as shown in Figure 3, the technology reaches the *plateau of productivity*, where its benefits are widely recognized and adoption stabilizes. This stage is characterized by widespread use, integration into routine processes, and ongoing optimization (Gartner, n.d.).

Figure 3. Gartner Hype Cycle for emerging technologies



Own illustration based on Chandrasekaran (2024)

Consequently, the evolution of emerging technologies is inherently dynamic and susceptible to continual transformation. Technologies may traverse these phases in disparate manners contingent on their context (Rotolo et al., 2015). The temporal dimension of the growth of an emerging technology is evaluated in studies through the quantification of related documents, including news articles and publications, over time (Cozzens et al., 2010). Furthermore, the issue of competition during the commercialization process represents a crucial element in this transformation process. Although emerging technologies are regarded as core technologies, they may not initially exhibit the capacity to alter competitive dynamics (Hung & Chu, 2006). However, emerging technologies have the

potential to either create entirely new industries or to transform existing ones in the long run, thereby indicating the broader economic and societal shifts accompanying their development (Day & Schoemaker, 2000).

Broader socio-economic transformations

The economic impact of emerging technologies is substantial and complex, affecting numerous sectors and reshaping broader socio-economic systems. Technologies such as artificial intelligence (AI), biotechnology, and nanotechnology are pivotal in facilitating transformation, stimulating innovation, and generating novel market opportunities. These innovations enhance productivity, competitiveness, and efficiency across a range of industries, including healthcare, manufacturing, agriculture, and energy (Bai et al., 2020). In the field of biotechnology, the advent of novel genetic engineering techniques has paved the way for the development of more sustainable agricultural practices and personalized treatments for diseases such as cancer and diabetes (Pham, 2018). These developments have the potential to improve healthcare outcomes (Bhatti et al., 2022) and generate economic benefits (Lokko et al., 2018). Moreover, AI is transforming healthcare through advances in personalized medicine, diagnostics, and drug development, while also transforming sectors like finance, logistics, and retail through automation and data-driven decision-making (Bajwa et al., 2021; Bekbolatova, M., Mayer, J., Ong, C. W., & Toma, M., 2024). Similarly, nanotechnology has the potential to enhance manufacturing processes, create new materials, and improve energy efficiency, which can significantly reduce production costs and foster green innovations (Iavicoli et al., 2014; Malik et al., 2023).

However, the economic implications of these technologies are not limited to sectoral growth; rather, they extend to the transformation of entire industries. As evidenced by numerous examples, emerging technologies have the potential to create new markets, disrupt existing ones, and expand knowledge bases across industries (Bower & Christensen, 1995). Moreover, they contribute to economic growth through market innovation and the fostering of competition via the development of novel business models (Day & Schoemaker, 2000; Porter et al., 2002). In order to fully realize the economic potential of these innovations, it is essential to invest in infrastructure and align policy accordingly. Emerging technologies have considerable potential to facilitate sustainable development, offering the possibility of enhanced efficiency, reduced costs, and responses to global challenges such as climate change (Alnahhal et al., 2024; Schwab, 2017; Swart et al., 2003). The integration of AI and IoT, for instance, can optimize energy usage in industries such

as manufacturing, thereby reducing carbon footprints while simultaneously enhancing profitability (Alalwan et al., 2024). Furthermore, AI-powered solutions in agriculture and logistics have the potential to optimize resource distribution, thereby reducing waste and improving supply chain efficiency (Elufioye et al., 2024). Consequently, the economic effects of emerging technologies are not only immediate but also long-term, with the capacity to fundamentally reshape the global economic landscape, influencing everything from job markets to international trade dynamics (Favaro et al., 2022).

As previously stated, the potential of emerging technologies to generate entirely novel industries or radically alter existing ones represents a further consequence of their ability to facilitate substantial change. The digital revolution has redefined a number of industries, including media, retail, and finance (Day & Schoemaker, 2000). For example, the advent of the Internet has not only given rise to sectors such as e-commerce and digital marketing, but has also fundamentally altered the operations and business models of traditional industries, influencing global economic growth (Cusumano & Goeldi, 2013). Information and communication technologies (ICT) provide an illustrative case of this phenomenon. On average, ICT investment has a significant impact on maintaining stable rates of gross domestic product (GDP) growth. However, there is no conclusive evidence regarding the consistency of this effect across ICT domains, such as cell phones, computer technology, and Internet access (Niebel, 2018).

Furthermore, the relationship between ICT investment and GDP growth varies across countries with different levels of economic development (Niebel, 2018; Stanley et al., 2018). Nevertheless, the emergence of new markets has the potential to transform industries, particularly those where technological advancement is a primary source of competitive advantage (Hung & Chu, 2006). It is evident that firms which adopt and integrate emerging technologies successfully are more likely to outperform their competitors. Conversely, those that fail to adapt may suffer a reduction in market share or become obsolete (Qian & Wang, 2017). The far-reaching impact of emerging technologies can be observed at numerous levels within the socio-economic system, affecting not only specific industries but also larger-scale organizations, institutions, and entire economies (Ciarli et al., 2021). In addition to industrial transformations, emerging technologies are influencing the broader socio-economic system in numerous ways. Primarily, they facilitate the optimization of knowledge production processes, accelerating research and development (R&D) and fostering innovation across disciplines (European Commission et al., 2019). Furthermore, the adoption of advanced technologies frequently requires

modifications to regulatory frameworks, labor markets, and educational systems, resulting in more extensive transformations in technological regimes (Corrocher et al., 2003).

2.3 Sociological Context of Technology and Innovation

The societal implications of emerging technologies are profound, influencing not only how these innovations are adopted but also how they shape and are shaped by the communities in which they operate. Emerging technologies, while offering the potential to improve efficiency and drive economic growth, often come with unintended *ecological* and *societal* consequences (Alexander, 1985). For instance, AI and the Internet of Things (IoT) have demonstrated remarkable potential for enhancing energy efficiency in industrial processes, such as optimizing supply chains and reducing resource consumption in manufacturing (Tomazzoli et al., 2023). However, these technologies also give rise to concerns regarding electronic waste and the environmental impact of their production (Wang et al., 2024). These challenges highlight the necessity of adopting life-cycle thinking — an approach that considers the environmental impacts of technologies from production to disposal (Arvidsson et al., 2018). Engaging the public and relevant stakeholders in these discussions has been discussed to ensure a balanced perspective on the benefits and ecological costs associated with technological innovations (Ezeh et al., 2024).

Key elements in the diffusion of innovations

Concerning the dissemination of technologies⁷ within society, Everett M. Rogers' "Diffusion of Innovations"⁸ (2003) framework can be regarded as a foundational work that can inform this context. Rogers describes the diffusion of innovations as a process whereby new ideas are communicated over time within a social system. This occurs as a result of five key elements (E. M. Rogers, 2003). The first element is the *innovation* itself, in this context new inventions or novel technologies are the recombination of pre-existing technological components to have a wide impact on industry and economy (Arthur, 2009; Schumpeter, 1976). As E. M. Rogers (2003) reviews, certain characteristics of *innovations* influence their rate of adoption. Thus, the component of *relative advantage* of innovation refers to the perceived benefit of the innovation over existing solutions,

⁷ In addressing the distinction between innovation and technology, E. M. Rogers (2003) observes that novel concepts are regarded as technological innovations, and are thus employed interchangeably with the terms “innovation” and “technology”.

⁸ The seminal work of Rogers' Diffusion of Innovations can be traced back to 1962, this book refers to the fifth edition of Rogers' (2003) work.

encompassing factors such as economic benefits, social prestige, convenience, or user satisfaction (E. M. Rogers, 2003). Science-based inventions diffuse faster than less science-oriented ones, as supported by prior studies (Bacchiocchi & Montobbio, 2009). The diffusion of technology takes place in a research and development (R&D) process where the innovation is improved and adapted to different environments, to be adopted by users (R. R. Nelson et al., 2004). However, uncertainty surrounding the benefits, costs, or longevity of an innovation can slow down its adoption, challenging the assumption that the diffusion process is linear (Hall, 2004; N. Rosenberg, 1972). An investment decision is done based on the decision makers' available information (Hall, 2004). For example high science-intensity patents in both biotechnology and semiconductors diffuse faster due to knowledge based scientific norms like "communalism" and "primacy of first publication," though high intensity doesn't always correlate with the highest citations (Hohberger, 2016).

Another element in the diffusion process is *compatibility*, which is determined by the extent to which the innovation aligns with the existing values, experiences, and needs of potential adopters. Innovations that are at odds with social or cultural norms often face a more protracted adoption process (E. M. Rogers, 2003). The extent to which innovation is perceived as being difficult to understand or use is determined by its *complexity*, which in turn influences the rate of adoption. Simpler innovations are more likely to be adopted quickly, while complex ones face slower uptake due to the need for new skills or understanding (E. M. Rogers, 2003). Furthermore, *trialability*, defined as the extent to which an innovation can be tested or experimented on a limited basis, is another crucial factor in this process (E. M. Rogers, 2003). Innovations that allow for limited trials reduce uncertainty and encourage quicker adoption (E. M. Rogers, 2003). Additionally, *observability*, defined as the extent to which the outcomes of an innovation are perceptible to others, has been shown to stimulate faster adoption through peer influence and discussion, as easily observable benefits or outcomes are more likely to be disseminated and emulated at a faster rate (E. M. Rogers, 2003).

An essential aspect to consider in the innovation diffusion process are "*communication channels*", described as a communication process where new ideas are shared between individuals or groups (E. M. Rogers, 2003). This understanding is derived from the field of communication studies, wherein the concept of diffusion is regarded as analogous to the communication process delineated in Lasswell's (1948) formula. Within this theoretical framework, the inventor can be conceptualized as the originator of

information, the innovation components as the message, propagated through diffusion channels (E. M. Rogers, 2003). The adopter, in turn, can be regarded as the recipient of communication, with the outcome of adoption serving as the critical metric (E. M. Rogers & Shoemaker, 1971). Empirical evidence has demonstrated that mass media channels have been observed to be remarkably effective in fostering awareness among large populations, for example in the context of emerging technologies (Bauer, 2005). In contrast, according to E. M. Rogers (2003), interpersonal channels have been evidenced to be often more persuasive, particularly when targeting individuals with close social ties, because the adoption decisions of most individuals are based on subjective evaluations shared by peers who have already adopted, emphasizing the role of modeling and imitation within social networks (E. M. Rogers, 2003).

Moreover, the *time* dimension is integral to the diffusion process, as this process delineates the trajectory of an individual's progression from the initial awareness of an innovation to its subsequent adoption or rejection (E. M. Rogers, 2003). Furthermore, the temporal dimension facilitates the evaluation of innovativeness, signifying the temporal synchrony of an individual's or a group's adoption of an innovation relative to others (E. M. Rogers, 2003). Additionally, the temporal aspect is instrumental in quantifying the rate of adoption within a system, thereby determining the rapidity with which an innovation disseminates over a specified interval (E. M. Rogers, 2003).

The *social system* can be defined as a set of interrelated units, such as individuals, groups, or organizations, working together to solve a common problem and achieve a shared goal (E. M. Rogers, 2003). Herein, the system's structure influences how an innovation spreads within it, with key factors including the impact of social norms, the roles of opinion leaders and change agents, the types of innovation decisions, and the consequences of the innovation (E. M. Rogers, 2003). Collectively, these elements shape the diffusion process, with the social structure setting the boundaries within which an innovation is adopted (E. M. Rogers, 2003). Overall, the rate of adoption, as defined by steps described above, is measured by the period required for a specified percentage of system constituents to adopt the innovation. This measurement is used as an indicator of the relative rate of adoption in a given social system (E. M. Rogers, 2003).

In addition, the “*innovation-decision process*” constitutes the series of four steps an individual or organization undertakes when determining whether to adopt or reject a novel concept (E. M. Rogers, 2003). *Awareness of knowledge* refers to the first stage of knowledge in the innovation-decision process, at which point an individual becomes

aware of the existence of a new innovation or idea. At this stage, individuals may not yet have a comprehensive understanding of the innovation's full potential, but they have been exposed to it through various means (E. M. Rogers, 2003). Awareness knowledge is often gained through mass media, advertisements, or word-of-mouth communication. This awareness serves as a catalyst, igniting curiosity and prompting further exploration of the innovation (E. M. Rogers, 2003). The second category of knowledge was characterized as '*how-to knowledge*', which denotes the practical information necessary for the effective utilization of an innovation, including the comprehension of its appropriate quantity and application. It was asserted that complex innovations necessitate a greater degree of 'how-to knowledge', and a dearth of this knowledge can result in the rejection or discontinuation of the innovation (E. M. Rogers, 2003). An individual's understanding of the fundamental principles that enable an innovation to function is referred to as "*principles knowledge*". While the adoption of innovations can occur independent of this knowledge, an absence thereof can heighten the risk of misuse and potentially result in its cessation. The possession of principles knowledge, however, enables individuals to make informed decisions and enhances their capacity to evaluate future innovations (E. M. Rogers, 2003).

Considered as the second phase of *the* innovation-decision process is the *persuasion* stage, during which an individual begins to form a favorable or unfavorable attitude toward the innovation (E. M. Rogers, 2003). This stage is more affective, meaning it is focused on feelings, than the knowledge stage, where cognitive understanding occurs. Individuals seek information about the innovation, and selective perception influences how they interpret this information. Factors such as relative advantage, compatibility, and complexity are key in shaping attitudes (E. M. Rogers, 2003). The uncertainty surrounding the potential outcomes of an innovation can motivate individuals to seek social reinforcement from their peers rather than relying solely on mass media. As a result of the persuasion stage, a "cue-to-action" can occur from an event that transpires at a specific moment, during which a favorable attitude is solidified into overt behavioral modification (E. M. Rogers, 2003). However, while the persuasion stage can lead to an attitude change, it does not always result in immediate adoption. A prevalent phenomenon, the "KAP-gap" (knowledge-attitude-practice) emerges when individuals express favorable attitudes towards an innovation but do not adopt it, as evidenced by the low adoption rates of contraceptives in certain countries (E. M. Rogers, 2003).

In the subsequent stage, the *decision stage*, an individual elects to either adopt or reject an innovation (E. M. Rogers, 2003). Adoption signifies complete integration of the

innovation, whereas rejection entails the decision not to adopt it (E. M. Rogers, 2003). To mitigate uncertainty, many individuals experiment with innovations on a limited scale prior to making a definitive decision, a process frequently termed a trial. Innovations that can be tested in parts are typically adopted more expeditiously (E. M. Rogers, 2003). Trial methods, such as offering free samples, can expedite the adoption process. In some cases, observing peers who have already adopted an innovation can serve as a substitute for personal trial, a concept known as "trial by others" (E. M. Rogers, 2003). However, the decision process can also lead to rejection, either actively (after considering or testing the innovation) or passively (by not considering it at all). Rejection can occur at any stage, even after an initial decision to adopt, leading to discontinuance (E. M. Rogers, 2003).

Furthermore, the *implementation stage* is characterized by the initiation of the practical application of an innovation by an individual or organization, thereby diverging from earlier stages in which innovation is merely conceptualized (E. M. Rogers, 2003). This stage entails tangible actions and behavioral modifications, in contrast to the earlier stages which are predominantly mental decision-making processes. Notwithstanding the resolution of the adoption decision, the uncertainty surrounding the effective utilization of the innovation may persist, prompting individuals to seek answers regarding the acquisition, implementation, and resolution of any operational challenges associated with the innovation (E. M. Rogers, 2003). Within organizational settings, implementation can be more complicated due to the involvement of multiple individuals and the potential for resistance from the organization's structure. The implementation stage is concluded when the innovation becomes a standard, institutionalized component of the adopter's routine. This process is frequently referred to as routinization or institutionalization (E. M. Rogers, 2003). In certain instances, re-invention, which involves modifying the innovation to align more closely with the adopter's needs, may occur during this stage. However, the culmination of the implementation stage signifies the conclusion of the innovation-decision process for many individuals, although some may proceed to an additional confirmation stage (E. M. Rogers, 2003).

The final stage of the innovation-decision process is the *confirmation stage*, which occurs subsequent to the determination of adoption or rejection of the innovation (E. M. Rogers, 2003). During this stage, individuals seek reinforcement for their decision yet may reverse it if they encounter conflicting information (E. M. Rogers, 2003). Individuals often seek information that supports their decision, a phenomenon known as selective exposure (Stroud, 2017) carried out in a way to avoid cognitive dissonance (Festinger,

1957). Such dissonance can emerge in various stages of the innovation adoption process, including the initial knowledge stage, when individuals seek information about the innovation; the decision and implementation stage, when individuals exhibit a favorable attitude toward the innovation but do not adopt it, or after adoption, when doubts arise and lead to discontinuance or subsequent adoption. In this context, *change agents* play a key role by providing reinforcement to prevent discontinuation, as negative messages about the innovation can influence adopters' commitment (E. M. Rogers, 2003).

Rate of innovation adoption and adopter categories

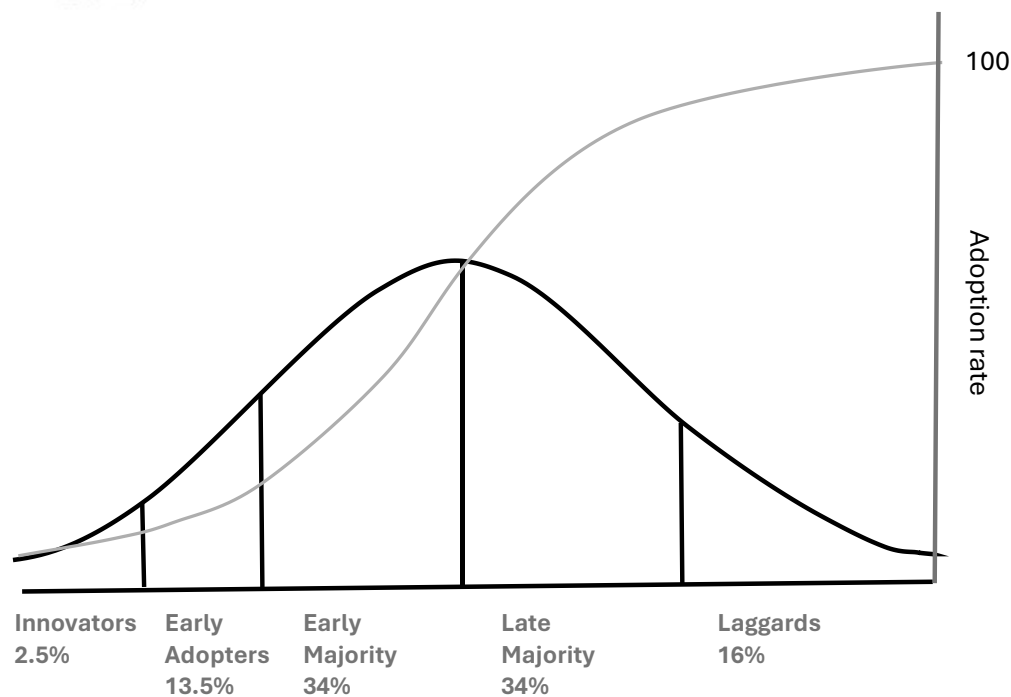
However, innovations can be modified in the process of adoption and implementation, which is summarized under the concept of reinvention. Nevertheless, some innovations, such as hybrid corn, resist change because of their rigid design (E. M. Rogers, 2003). *Adoption rate* is defined as the relative speed with which an innovation is adopted by members of a social system (E. M. Rogers, 2003). It is typically measured in terms of the number of individuals who adopt the innovation in a social system over a given period of time, and this rate is reflected in the steepness of the adoption curve, which follows either a bell-shaped (frequency) or an S-shaped (cumulative) curve (E. M. Rogers, 2003). As Figure 4 illustrates that the S-shaped curve is a widely used representation of the cumulative adoption of an innovation over time. It is shown how adoption begins slowly, accelerates during an intermediate phase, and eventually levels off as most members of a social system adopt the innovation (E. M. Rogers, 2003). Initially, only a few individuals, known as innovators, adopt the new idea. These *early adopters* are typically willing to take risks or have the resources to experiment with unproven innovations (E. M. Rogers, 2003).

During this period, the rate of adoption remains low due to limited awareness and perceived uncertainty surrounding the innovation. As more people observe the success of these early adopters, the rate of adoption accelerates, marking the beginning of a middle phase (E. M. Rogers, 2003). This phase, often referred to as the takeoff phase, is characterized by rapid growth as the *early majority* begins to adopt the innovation (E. M. Rogers, 2003). Their decision to adopt is influenced by the positive experiences of innovators and early adopters, which help reduce uncertainty. This phase is often characterized by a steep upward slope of the S-shaped curve. Subsequently, the rate of adoption slows as the *late majority* and *laggards* begin to adopt (E. M. Rogers, 2003). These groups tend to be more cautious or resistant to change, adopting only after the innovation has become

widely accepted or necessary. At this point, cumulative adoption reaches a saturation level, and the curve flattens. The majority of the social system has adopted the innovation, leaving little room for new adopters (E. M. Rogers, 2003).

Adopter categories vary in terms of innovativeness, socioeconomic status, communication behavior, attitudes toward risk and change, and their role within the social system (E. M. Rogers, 2003). As shown in Figure 4, *innovators* are the first 2.5% to adopt an innovation, highly adventurous and willing to take risks with new ideas. They have a high socioeconomic status, are described as well-connected cosmopolitans, and often act as gatekeepers for innovation. The group of *early adopters* (13.5%) are considered opinion leaders within the social system, valued for their critical evaluation of new concepts, and adopted after careful consideration. These individuals hold relatively high status within their respective social systems, make extensive use of interpersonal communication, and serve as role models for others. Adopters in the *early majority* category (34%), referred to as deliberate adopters, adopt only after observing the initial success of an innovation and only when there is a sufficient critical mass of adopters. As such, these adopters have an average socioeconomic status (SES), rely on the social system for communication, and play a critical role in the adoption process. In addition, adopters in the *late majority* category (34%) adopt innovations only after careful consideration and often serve as role models for others. In terms of social class, the subjects of this category have an average SES, and they rely on communication within the social system. The least likely to adopt an innovation are *laggards* (16%), who show strong resistance to change and a preference for traditional methods. Low socioeconomic status, limited exposure to modern communication, and the adoption of technology only when absolutely necessary are characteristics of this group (E. M. Rogers, 2003).

Figure 4. The diffusion of innovation and adopter categories



Own illustration based on E. M. Rogers (2003)

Criticism and application of the diffusion of innovation

In his work, Rogers discussed the "pro-innovation bias," defined as an overly optimistic view of innovation in which an invention is neither reinvented nor rejected (E. M. Rogers, 2003). This understanding includes the assumption that new ideas or technologies are inherently beneficial and should be adopted without sufficient consideration of potential negative effects (E. M. Rogers, 2003). Rogers criticizes this bias, arguing that innovations are not always universally beneficial and that their effects can vary across contexts, cultures, and groups (E. M. Rogers, 2003). For example, a study by Dutta and Sarma (2020) on the adoption of digital innovations in India found that while many respondents were not significantly affected by the digital transition, the adopters fell primarily into the categories of early adopters and early majority. While these users are aware of incremental innovations, they remain skeptical about their use. Moreover, although information and communication technologies (ICTs) had been used in practice in the early 20th century, they had not been widely adopted by user groups. This finding underscores the notion that the initial reasons for adopting a technology may differ from its actual use in everyday life (Frissen, 2000). In the context of consumer preferences regarding electric vehicles (EVs), four distinct groups could be identified related to actual EV users, potential

buyers, interested consumers, and uninterested consumers. An analysis revealed significant socio-demographic differences between early adopters (users and intenders) and those less inclined to adopt (interested and uninterested). This suggests that it is possible to identify early target groups for EVs. But it also highlights that electric vehicles currently appeal to certain demographics, with groups such as women exhibiting less early interest (A. Peters & Dütschke, 2014).

E. M. Rogers and Shoemaker (1971) introduced an approach to reviewing studies as "meta-research," which aimed to make generalizations about innovation by aggregating findings from different studies. However, this method has been subject to considerable criticism (see for example Schmidt, 1976). First, Rogers' approach of counting how many studies support a particular claim without considering factors such as sample size, effect size, or methodological differences can lead to bias (G. W. Downs & Mohr, 1976). In addition, the phenomenon of publication bias, whereby studies with significant results are more likely to be published, may exacerbate hypothesis confirmation. It was also argued that Rogers' interpretation of the proportion of confirming findings as an indicator of the validity of a theory, where he stated that 70% confirmation is sufficient, would be problematic from a critical rationalist perspective (E. M. Rogers, 2003). Furthermore, causal inference in diffusion research has been based on cross-sectional survey data, which cannot establish a temporal sequence or a causal relationship between independent variables and innovativeness. To remedy this, it has been argued that researchers need to employ methodologies such as field experiments, longitudinal studies, and point-of-adoption studies to enhance the understanding of causal relationships and mitigate recall bias in diffusion research (E. M. Rogers, 2003).

Diffusion of Innovations (DOI) theory has had a significant impact on other areas of research and application, such as influencing social psychological theories of behavior, particularly in understanding individual adoption decisions. Early models such as the Theory of Reasoned Action (TRA)⁹ by Fishbein and Ajzen (1975) and Theory of Planned Behavior (TPB) by Ajzen (1985) incorporated beliefs and evaluations into adoption decisions. Later approaches, such as the Technology Acceptance Model (TAM) (F. D. Davis, 1989) and Unified Theory of Adoption and Use of Technology (UTAUT) (Venkatesh et al., 2003), built on DOI concepts to better predict technology adoption behavior by

⁹ See chapter 3.1.2 for the discussion of theoretical models on the behavioral dimension of attitude formation.

integrating its key elements, including innovation attributes like relative advantage, compatibility, and complexity (Venkatesh et al., 2003).

Principles of the Social Construction of Technology (SCOT)

While the diffusion of innovations (DOI) theory emphasizes the processes and factors that influence the rate of adoption, the Social Construction of Technology (SCOT) framework (Pinch & Bijker, 1984) underlines the importance of considering the ways in which innovations are understood and used, which can vary across different social contexts. SCOT posits that the meaning and functionality of an innovation are not fixed but are shaped by the social groups that adopt it. In this sense, SCOT adds depth to the diffusion of innovations model by showing that the adoption process is influenced by users' social interactions and interpretations, thereby deepening our understanding of how innovations evolve and adapt to meet the needs of different adopter groups over time. This reinforces the idea that adoption is not just a linear process, but one that is socially constructed and context dependent (Pinch & Bijker, 1984).

How innovations are modified in social contexts has been studied in the tradition of Science and Technology Studies (STS) since the 1980s, when a number of sociological studies investigated the Social Construction of Technology (referred to as "SCOT") (Pinch & Bijker, 1984). The primary premise of the social constructivist approach is that technology is shaped by the social, and contextual factors that influence its development (Pinch & Bijker, 1984). Overall, the social construction of technology framework has four main principles, the first principle of *interpretive flexibility* suggests that the design of technology is not fixed but rather shaped by social circumstances and negotiations among social groups. SCOT scholars argue that technological artifacts are similarly shaped by intergroup negotiations which leads to the conclusion that technological designs are inherently flexible and could have resulted in alternative forms. Examples of this perspective include studies on early bicycles (Bijker, 1995) and fluorescent lighting (Bijker, 1992). Work on the social construction of technology is viewed as a multidirectional model, emphasizing the notion that technology is a product of the collective efforts of a variety of socially relevant groups, including engineers, users, and strategists, which collectively influence the trajectory of technological innovation (Pinch & Bijker, 1984).

The interaction between relevant *social groups* as the second key principle is a crucial aspect of the closure process, as certain groups "share the same set of meanings attached to a particular artifact". Social groups can be seen as actors with different

interpretations of these scientific artifacts (Klein & Kleinman, 2002; Pinch & Bijker, 1984). Moreover, in a process of *closure* and *stabilization*, conflicting interpretations from social groups can lead to controversy until a technology is stabilized by the consensus of these groups on its form and function (Klein & Kleinman, 2002). Once the multi-group process is complete and a technology has reached a state of stabilization, it becomes less susceptible to further change in the sense that unresolved problems are redefined so that they no longer pose problems to social groups, effectively solidifying its position within society (Klein & Kleinman, 2002; Pinch & Bijker, 1984). There is also the *wider context*, which refers to the broader socio-cultural and political environment in which technological development takes place. While this aspect was minimally addressed in Pinch and Bijker's original framework, it includes factors such as power dynamics, group relations, and the rules that govern interactions. Subsequent critiques of SCOT have largely focused on this area, highlighting the need for greater attention to these structural influences (Klein & Kleinman, 2002).

Another noteworthy contribution of this work is the concept of *technological frame* or “a frame with respect to technology” (Bijker, 1995, p. 126). Importantly, these frames are situated between actors which refers to the shared beliefs and goals among the actors of a social group that shape how they perceive and interact with an artifact respective technology (Bijker, 1995). This process influences the decisions made during the development of a technology, determining what problems it should address and how it should be designed. For example, celluloid as a technology was influenced by a relevant social group of “celluloid chemists” whose interactions were structured by a new technological frame. Elements of a technology frame according to Bijker (1995), are “goals, key problems, problem-solving strategies (heuristics), requirements to be met by problem solutions, current theories, tacit knowledge, testing procedures, and design methods and criteria” (p.123).

For example, the technology frame of celluloid refers to chemists' goal of producing a substitute for plastic to make fancy items. However, when the artifact of celluloid was stabilized, key problems were the price of the solvent and the properties of the materials such as flammability and its modeling characteristics. To overcome these critical aspects, the solvent was modified in reaction by applying criteria from natural plastics, such as price and lack of shrinkage. Although there was no chemical theory involved in the interaction of chemical scientists, tactical knowledge was used with the application of heat and pressure to reach a specific maximum to not damage the material. In addition to

technologists, these technology frameworks must be universally applicable to scientists as well as non-experts, such as consumers. As artifacts stabilize, criteria are defined by actors about the artifact as a working machine (Bijker, 1995). Nanotechnology serves as a valuable example for SCOT processes because it is an emerging technology that is in the process of being defined and shaped by social and technical problems, requiring investment, coordination, and collaboration among different actors such as governments, universities, and industry. This reflects the interpretive flexibility central to SCOT, where different social groups influence the trajectory of a technology based on their goals, priorities, and problem-solving approaches (Cutcliffe et al., 2012). A key argument is that innovation in nanotechnology depends on interactions between different frames — zones or groups that typically do not work together but must now exchange ideas. For instance, governments, rather than markets, may define "worthy" problems that need deliberate ethical consideration. This aligns with Bijker's analysis of Bakelite, where outsider groups were drawn into solving technological challenges that traditionally fell outside their domains (Bijker, 1995).

As Klein and Kleinman (2002) have argued, Bijker's introduction of the technological frame into the SCOT framework represents an important step toward acknowledging the role of structure in technological development. While Bijker's work highlights the shared understandings and practices within social groups, it employs an "agency-centered" approach that does not sufficiently account for the broader structural forces—such as power dynamics, cultural norms, and economic systems—that shape technological development in more profound ways (see Klein & Kleinman, 2002). Technology and technological change being shaped by social groups refers to the establishment and influence of social relations that may be in conflict, such that technological change is never a "socially neutral process" (Hård, 1993, p. 416). For example, Kline and Pinch (1996) demonstrated how gender roles influenced the redesign of the rural automobile, showing that men, as technical experts, adapted cars for practical purposes, while women were excluded from design processes and limited to operating the machines. While insightful, this analysis remains narrowly focused on gender and lacks a broader interrogation of how other structural factors—such as class, race, or institutional power—interact in technological development (Klein & Kleinman, 2002).

One of the primary criticisms of the SCOT methodology is its perceived lack of flexibility and overly standardized approach. Critics argue that SCOT's strict application of concepts, such as relevant social groups, and technological frame, limits the space for

imagination, creativity, and novel insights. Rather than fostering innovative analysis, it may produce repetitive and generic studies (Winner, 1993). Moreover, a key criticism of SCOT is its avoidance of normative issues and its commitment to value neutrality, which critics argue stems from its reliance on interpretive flexibility. By refusing to ascribe meaning or essence to artifacts, SCOT avoids addressing the moral, political, or human welfare implications of technologies (Winner, 1993). Thus, it has been argued to integrate the public's role in shaping views of technology, with the public actively involved in assessing risks, costs, and benefits before publicly funded technologies are fully developed (Arnall & Parr, 2005). For instance, public understanding and framing of the values associated with nanotechnology highlights the social constitution of this emerging technology (C. Lee et al., 2005).

2.4 Policy and Regulatory Context

Technology governance for emerging technologies faces unique challenges (World Economic Forum, 2019). First, the rapid pace of their diffusion, driven by digital networks, leads to immediate cross-border impacts and renders traditional policy processes inadequate (Guston, 2013; OECD, 2024a). Technologies are also converging across sectors, such as the blending of biological and digital technologies, complicating governance (Fabiani et al., 2024; Jeong et al., 2015). Additionally, the personalized nature of many technologies, including short-term platforms, poses challenges in regulation once integrated into daily life, giving rise to strong interest groups that resist governance efforts (World Economic Forum, 2019). The values and assumptions of the creators of emerging technologies also influence their impact on society. For example, AI systems can perpetuate biases based on the data used to train them (World Economic Forum, 2019). Finally, the inherent uncertainty of these technologies complicates risk management when incorporating the views of a variety of stakeholders, presenting a challenge for policymakers (Klinke & Renn, 2010; Renn, 2015).

In essence, these challenges necessitate the implementation of a targeted technology governance, as defined by the OECD (2024a) as “The process of exercising political, economic and administrative authority in the development, diffusion and operation of technology in societies” (p.9) (see also OECD, 2012b, 2018). Technology governance involves norms, institutions, and physical or virtual frameworks that manage risks and benefits, shaped by governments, firms, civil society, and professional communities, each with distinct approaches (OECD, n.d.–a). The implementation of innovative policies in

turn aims to foster positive long-term trends in innovation performance and to avert potential long-term damage to innovation systems caused in the context of global challenges and crises (OECD, 2012a). In light of these complexities, it becomes essential to consider the key policy aims that can guide the governance of emerging technologies. The subsequent section delineates these policy objectives and strategies with regard to fundamental domains of emerging technologies.

As early as 2007, the European Commission stated that European research policy needs “experiment with new ways of involving society at large in the definition, implementation and evaluation of research agendas”(p.10). This growing awareness that technology governance has to adjust to the complex, interdisciplinary, and rapidly changing landscape of emerging technologies has also been reflected in recent work on governance of emerging technologies (Karinen & Guston, 2010; OECD, 2024a). For example, since 2014 the European Commission's flagship research program Horizon 2020, has addressed societal challenges such as climate change, health, and sustainable agriculture, by allocating funds to high-impact research initiatives (European Commission, 2018c). In a later framework, as evidenced by the European Commission (2018), the objectives of *supporting innovation, fostering research, and enhancing technological development* are described as to establish a context that is conducive to scientific discovery and technological progress.

To support essential goals of research development, the provision of financial resources, the construction of the necessary infrastructure, and the implementation of incentives are needed to ensure that technological advances ultimately contribute to economic growth and sustainable development (OECD, 2023; Ulnicane, 2022). For example the United Nations' 2030 Agenda for Sustainable Development (United Nations, 2015) outlines 17 goals to facilitate progress in the economic, social, and environmental areas that are central to sustainable development. To facilitate this transformation, governments are encouraged to incentivize innovation through mechanisms such as grants, tax benefits, and subsidies (OECD, 2017). The baseline for economic potential and knowledge intensity is to increase the number of researchers and public and private funding for *research and development (R&D)*. Priority areas for R&D investment include agriculture, healthcare (e.g., vaccines and medicines), clean energy (e.g., renewables and efficiency), and marine health (e.g., ocean biodiversity) (OECD, 2016).

However, as observed by the OECD (2016) public R&D budgets demonstrate disparate orientations with regard to sectors and regions. In 2023, the EU spent 381.4 billion

euros on research and development (R&D), while the R&D intensity of 19 EU countries showed an increase between 2013 and 2023. The business enterprise sector accounted for 66% of EU R&D spending, the higher education sector for 21%, the government sector for 11% and the private non-profit sector for 1% (eurostat, 2024). The EU invests heavily in renewable energy R&D, providing 35% of the Horizon Europe budget. Large economies lead in terms of total funding, while Nordic countries lead in terms of GDP (Gasser et al., 2022). In the regional context, these efforts include, for example, programs to promote green and digital transitions (Muench et al., 2022), to develop interconnected innovation ecosystems (European Commission: Directorate-General for Research and Innovation & Barrera, 2020), and to foster collaboration between national and regional entities (Uyarra et al., 2014). This underscores the importance of equitable participation across diverse regions and actors to ensure that the innovation benefits of emerging technologies are widely shared (European Commission, 2018c).

Another key aspect of policy papers is the promotion of *economic competitiveness* as a means to stimulate future expansion (European Commission, 2018c; OECD, 2016). As a consequence, governments and organizations are turning their attention to strategic technological leadership, such as investments in transformative digital technologies like artificial intelligence and robotics, with the aim of driving future economic growth (European Commission, 2024f). As an instrument to support innovation and regional development, cluster policy was used “to generate growth in the EU by unlocking new business opportunities in existing and new value chains and creates synergies through inter-regional and cross-sectoral cooperation (European Commission, 2018c, p. 46). Moreover, the standardization strategy aims to stimulate innovation and enhance competition by ensuring interoperability, reducing transaction costs, and facilitating the emergence of technological platforms, especially in network industries such as ICT. By establishing common standards, industries can strengthen their global competitiveness, and it is therefore imperative to coordinate with international bodies to create unified global standards, for example by better aligning European standards with international standards (European Commission, 2024g). However, incomplete ICT standardization poses significant challenges for businesses, leading to reduced profitability and a slowdown in the development of digital infrastructure, including broadband networks (European Commission, 2018c).

To illustrate the goal of stimulating economic growth, national policy strategies such as the UK Government's Innovation Strategy (2023) seek to leverage emerging technologies such as green energy and advanced digital infrastructure. The strategy focuses

on strengthening the UK's global position through the implementation of strategic investment initiatives in key technology sectors to promote technological leadership in innovation. It also aims to attract and retain investment in these key areas, thereby fostering a supportive ecosystem for scaling businesses. This is achieved by providing incentives such as grants, tax breaks, and public-private partnerships. These collective efforts aim to transform the UK into a global hub for sustainable and innovation-driven growth (UK Government, 2023). Market competitiveness is determined not only by a well-developed market structure, but also by the ability to generate revenues and reinvest in innovation. Large firms significantly outperform small and medium-sized enterprises (SMEs) in terms of revenue generation (Fabiani et al., 2024). Only a small number of medium-sized firms achieve a level of revenue that is comparable to that of large firms. This has been discussed as a major challenge for the EU, where SMEs play a central role. The EU faces competition from major economies such as the US and China, where larger companies dominate. In capital-intensive industries such as advanced manufacturing, the ability to generate cash flow internally and achieve economies of scale is crucial for maintaining long-term market share and growth (Fabiani et al., 2024).

In addition, *workforce development* has been articulated as an essential goal in the context of economic objectives related to emerging technologies. As such, promoting the skills of the workforce is a critical element in the context of economic development (Toner, 2011). This entails ensuring that educational and training programs are updated in a manner that aligns with the demands of a technology-driven economy (European Commission, 2009). Vocational training, industry-academia partnerships, and reskilling initiatives are essential to prepare the labor force for high-skill, high-demand roles (European Commission, 2009). Therefore, the overarching objective of these actions is to achieve long-term economic resilience, inclusive growth, and a workforce that is adequately prepared to meet future challenges (OECD, 2017, 2021b). The general aim of addressing the adoption of green technology is impeded by a number of factors, including underinvestment due to unpriced environmental costs, inadequate incentives for adoption, and systemic failures in innovation infrastructure and coordination (OECD, 2012a).

Responsible Research and Innovation (RRI) has been defined by the European Commission: Directorate-General for Research and Innovation and Schomberg (2011) as essential to ensure “a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable

products in order to allow a proper embedding of scientific and technological advances in our society” (p.9). However, major global challenges such as the 2008 economic crisis have disrupted business innovation and R&D, with impacts varying across countries and exposing pre-existing weaknesses in some regions and industries¹⁰ (OECD, 2012a). Demographic change processes are also altering the nature of science and technology, for example information and communication technology (ICT) applications, to help address the opportunities and challenges associated with the health and disability aspects of ageing populations (OECD, 2012a).

Anticipatory governance as a framework for proactive technology management

Anticipatory governance is a strategic framework that aims to manage emerging technologies and societal challenges through the proactive integration of *foresight*, *public engagement*, and *iterative policy adaptation* (Guston, 2013; OECD, 2024a). This approach emerged as a response to the limitations of traditional reactive governance models, which often fail to address the potential societal and ethical implications of innovations in a timely manner (Guston, 2013). The key differences between traditional policy making and anticipatory innovation governance are a different approach to evaluation, while traditional policy making focuses on end-state evaluation, anticipatory governance emphasizes ongoing evaluation that takes into account future impacts, such as changes in public values, with the aim of creating a balanced dialogue between innovation and public concerns (Karinen & Guston, 2010). In this sense, efforts such as the OECD's Framework for Anticipatory Governance provide a baseline for technological development in the context of emerging technologies in five steps as an orientation for actors to anticipate and get ahead of technology governance (OECD, 2024a).

1. Guiding values in the innovation process

The first principle of the anticipatory governance approach is for innovation actors to discuss values in specific technology contexts to ensure that technology governance is consistent with democratic principles to serve the public good (OECD, 2024a).

As shown in Figure 5, “*foundational values*” in this context represent shared commitments to ethical, political, economic, and cultural ideals that guide innovation as it

¹⁰ The global financial crisis had a disproportionately negative impact on European countries, while the BRIC countries (Brazil, the Russian Federation, India and the People's Republic of China), as well as Argentina, Colombia and Korea, continued to experience economic growth (OECD, 2012a).

adapts to societal and technological change. These values include *respect for human rights, safety and security*, which minimize risks to the economy, the environment, and human well-being; *privacy*, which ensures the protection of personal data and freedom from interference with fundamental rights; and *democratic values*, such as the rule of law, equality, participation in public life, and the promotion of the public interest. *Sustainable development* of technology is also essential, with a focus on protecting ecosystems, addressing climate change, and promoting human well-being. *Equity and inclusion* further emphasize fair treatment, the participation of marginalized groups, and the reduction of global technological disparities (OECD, 2024a).

In addition to these fundamental values, *technology-specific values* guide policy decisions tailored to specific technologies. These include *trustworthiness*, which implies that technologies, actors, and their decisions can be counted on to be accurate, reliable, and compliant. *Responsibility* involves the attribution of consequences of actions and decisions related to technologies, which have also been linked to accountability to society. It has also been emphasized that an open and honest description of information related to technology, with justifications and limitations, in accessible language, is necessary to ensure *transparency*. The value of *technology stewardship* emphasizes that those with sufficient expertise and knowledge have a duty to create and use technology in ways that are consistent with fundamental values. In addition, the value of *innovation for the public good* encompasses the promotion of societal benefits from technology innovation and the need to reduce unnecessary barriers to achieve this goal. Finally, *responsiveness* is needed to meet the expectation that promised technological outcomes will be delivered in a timely manner (OECD, 2024a). Consequently, innovation actors should strive to integrate the aforementioned values throughout the *innovation process*, which includes, but is not limited to, four phases: (1) agenda-setting and end-state evaluation, anticipation emphasizes ongoing evaluation that takes into account future impacts, such as changes in public values. Moreover, traditional governance measures use long policy cycles with predictable implementation, while anticipatory approaches recognize changing problem spaces and the unpredictability of cause-and-effect relationships. Therefore, these innovative governance approaches incorporate real-world experimentation and consider evolving stakeholder systems with subsequent changes over time (OECD, n.d.–a).

In the context of nanotechnology, anticipatory governance has been applied through actions such as public consultations, scenario planning, and regulatory foresight to ensure that societal concerns such as safety and equity are addressed early in the

technology's development (Guston, 2013). For instance, the U.S. National Nanotechnology Initiative (NNI) played a key role in funding research on the ethical, legal, and social implications (ELSI) of nanotechnology research and development (R&D) design, (2) the actual R&D phase, (3) early commercialization, and (4) diffusion and deployment (OECD, 2024a).

2. Strategic intelligence

Recognizing the unpredictable nature of emerging technologies, the OECD describes common forms of *strategic intelligence* that include comprehensive analysis and knowledge of the technology's potential developments and impacts, economic stakes, risks and benefits, and societal implications (OECD, 2024a). Anticipatory governance of emerging technologies begins with *horizon scanning*, a systematic exploration of emerging technological developments and signals to identify opportunities, threats, and socio-technical issues such as the digital or quantum divide. This process identifies areas of technological interest, key drivers of change, and potential impacts (OECD, 2024a). Once an area of interest is identified, a preliminary *diagnosis* assesses the need for deeper analysis by considering six dimensions. These include the level of *uncertainty*, where unclear trajectories may require additional information gathering, societal engagement, or governance efforts.

Risk and magnitude of impact are assessed by estimating the potential impact on fundamental and technology-specific values, the likelihood and severity of harm, and their reversibility. The *level of public concern* or *value conflict* is analyzed to determine whether public and political attention, hopes, concerns, or controversies warrant deeper engagement and evaluation. Also considered is the *pace of technology emergence*, assessing whether rapid development is occurring and whether it is consistent with societal goals. Furthermore, the *strategic importance* of the technology is examined to see if it aligns with national strategic goals, such as global competitiveness, crisis response, or green transitions. Finally, *governance gaps* are identified to determine whether existing regulatory or governance mechanisms are adequate or whether new measures are needed (OECD, 2024a). If further analysis is warranted, an *extended appraisal* is conducted to understand the technology's status, development directions, ethical and societal implications, and risks. This assessment provides strategic intelligence to support informed decision making without directly making policy decisions by using other strategic intelligence tools such as technology forecasting, technology assessment (TA), and emerging

risk assessment (OECD, 2024a). Finally, the diversity of expertise and perspectives has been described by the OECD (2024a) as a strength to identify and engage stakeholders who should participate in the appraisal policy process.

3. Stakeholder engagement

Policies have prioritized the active engagement of stakeholders and the wider society in the policymaking cycle because engaging *diverse actors* early in the technology development cycle enriches understanding of the issues, fosters trust, and aligns technological innovation with societal needs (OECD, 2024a; World Economic Forum, 2019). Attention must be paid to balancing different perspectives and preventing vocal stakeholders from dominating the process. Similar to anticipatory governance, which provides a proactive framework, the idea of *multistakeholder governance*, as proposed, for example, by the World Economic Forum (2019) and the OECD (2024a), underscores the importance of fostering collaboration among different stakeholders with respect to technology governance. Technological advances have highlighted the need for collaborative decision-making processes that integrate the perspectives and expertise of different groups (Winickoff et al., 2021). Thus, the proactive engagement of stakeholders and the wider society in the policy-making cycle has been described as an essential element (OECD, 2024a).

As technology governance takes place through a variety of actors, such as academic institutions and government, but also through the activities of companies, civil society organizations and communities of practice, each with different modalities to address the complex opportunities and challenges of balancing the interests of different parties (Green, 2014; Matti et al., 2022; OECD, 2024a). Moreover, policy strategy papers indicate the objective of facilitating clear communication between policymakers and the general public, with an emphasis on S&T literacy on emerging technologies for the purpose of translating scientific knowledge into action (Holdren, 2008; Holdren et al., 2011). Accordingly, public engagement with science has been a subject of research and innovation (R&I) in EU programs like Horizon 2020. In accordance with the Open Science principles, these programs mandate citizen engagement through co-design and co-creation (European Commission: Directorate-General for Research and Innovation and Billgren Askwall, C., 2024). Anticipatory engagement tools for upstream societal engagement include *capacity building*, such as science communication and media training, and *consultation* and *co-creation* in the construction of science and technology and policy-relevant knowledge, such as collaborative platforms or "living labs" (OECD, 2024a).

4. Agile regulation

Given the fast pace and evolving nature of emerging technologies, governance systems must strive for *agility and anticipation* by adapting regulatory tools and ensuring responsiveness to stakeholder concerns (OECD, 2024a). The OECD (2021a) “Recommendation for Agile Regulatory Governance to Harness Innovation” stressed the need to adjust regulatory management tools to ensure that regulations are fit for purpose, to employ institutional foundations to enable co-operation, to develop or adapt governance frameworks to enable the development of agile regulation, and to adapt regulatory enforcement strategies to evolving needs.

Regulatory experimentation, such as innovation testbeds and regulatory sandboxes, allow for real-world testing of emerging technologies and policy options to improve their understanding of risks and opportunities. This approach, when combined with traditional tools such as impact assessments and stakeholder engagement, promotes adaptive learning, effective public policy, and better evidence. However, it has been noted that experimentation must be carefully coordinated, taking into account legal, feasibility and equity constraints, and be tailored to the maturity of the technology in order to ensure maximum benefits (OECD, 2024a). To ensure *responsible innovation*, the private sector has to be incentivized early in the development process, with a focus on empowering diverse perspectives in R&D, promoting responsibility principles, and embracing "ethics-by-design" approaches. Other strategies include incentivizing responsible investment, applying responsible business conduct principles, and aligning technology development with corporate social responsibility frameworks to ensure broad accountability (OECD, 2024a).

5. International co-operation

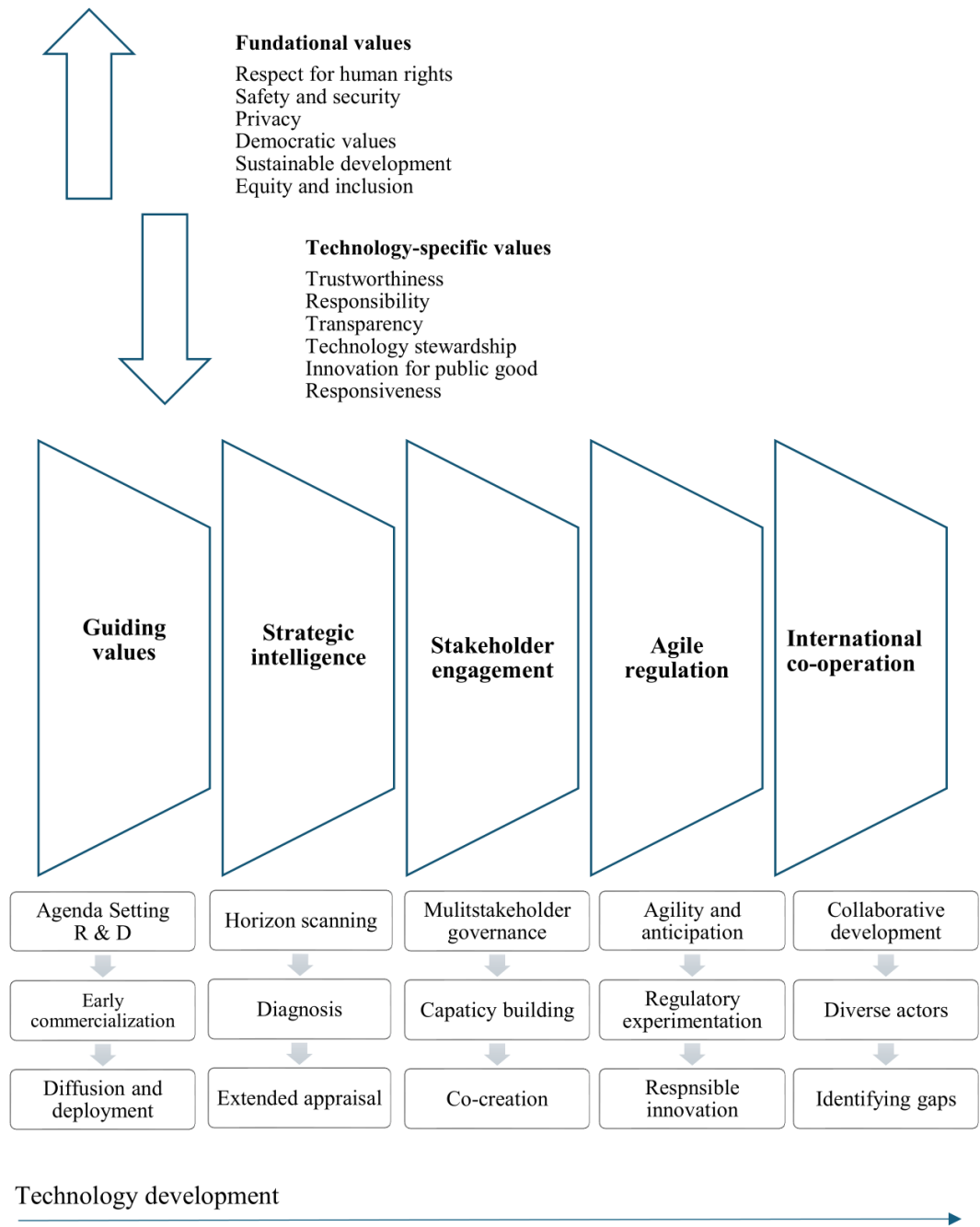
Acknowledging the transboundary nature of technology, international cooperation in science and technology is essential for advancing emerging technology governance. Efforts by organizations such as the OECD, UNESCO, and G7 promote *collaborative technology development* while establishing common ethical practices and governance norms (2024a). Forward-looking dialogue in inclusive fora can be facilitated by coordinating approaches to emerging technology governance, sharing experiences, deepening understanding, and laying the groundwork for collective standard-setting (OECD, 2024a). The OECD (2024a) highlights the importance of engaging *diverse actors* early in the technology development cycle, to help align innovation with public needs and foster trust. A recent

example initiative is the OECD Global Forum on Technology (OECD, n.d.–b, 2024a), launched in 2023, which brings together OECD members and partners and aims to facilitate regular, in-depth discussions on the long-term opportunities and risks associated with emerging technologies. This initiative focuses on *identifying gaps* in understanding the social, economic, security, and sustainability implications of technological developments and critically analyzes existing discourse on them. It moreover seeks to explore innovative policy frameworks and share evidence-based best practices for the governance of emerging technologies, with the aim of building trust and fostering collaborative, democratic, and coherent strategies to address these complex challenges (OECD, 2024a).

Overall, anticipatory governance aims to prioritize inclusivity, with a focus on balancing power dynamics among stakeholders and ensuring that marginalized voices are not overlooked. However, the role of public participation in science and technology policy has shifted significantly in recent years. According to Macq et al. (2020), from 2000 to 2010, the focus of public participation was on fostering inclusive dialogue to democratize policymaking. This period was marked by a crisis of legitimacy that spurred efforts to rebuild public trust in science and technology institutions. From 2010 to 2014, the focus shifted to fostering innovation, driven by the need for economic recovery, alongside hierarchical institutional dynamics. More recently, from 2014 to the present, there has been a greater emphasis on active public involvement in knowledge production and technological innovation (Macq et al., 2020). This shift is consistent with broader trends such as open science and co-creation, where collaborative efforts are seen as key to addressing global challenges (OECD, 2024a).

As the public becomes more involved in co-creating policy, governance must reflect these changes by embracing more collaborative models that give citizens a meaningful voice in shaping technological futures (Macq et al., 2020). Deliberative democratic processes, such as town hall meetings or deliberative polling, provide a means for diverse stakeholders to engage in ethical discussions about emerging technologies (OECD, 2022; World Economic Forum, 2019). Although policy and governance frameworks are imperative for shaping the societal trajectories of emerging technologies, their effectiveness is contingent upon a comprehensive understanding and acknowledgement of public perceptions of science and technology (D. A. Scheufele et al., 2021). The subsequent section explores these dynamics by examining science communication approaches that offer insight into the manner in which public perception is constructed and mediated through various strategies and frameworks.

Figure 5. Elements and strategies of anticipatory governance of emerging technologies



Own illustration based on the framework for anticipatory governance of emerging technologies by the OECD (2024a)

2.5 Science Communication Models and Perspectives

The *public perception of science and technology* has been the subject of extensive research, with the term defined as a broader conceptual category representing public opinion or attitude formation (Brossard & Nisbet, 2007; D. A. Scheufele & Lewenstein, 2005). As Bauer et al. (2000) noted, under the concepts of the public understanding of science and scientific literacy, the areas of *interest in science*, *knowledge of science*, and *attitudes to science* can be distinguished. T. W. Burns et al. (2003) defined the main purposes of science communication as to foster awareness, enjoyment, interest, opinion formation, and understanding. However, for the following investigation the focus will be placed on *attitudes* and *attitude formation* towards emerging technologies. The concept of *attitude formation* describes when individuals encounter new information or perspectives that they have not previously considered, leading them to form an initial attitude toward an issue, product, or concept (M. A. Hamilton et al., 1993). Science communication might encompass exposure to information, media coverage, and the framing of scientific messages. Science communication at this stage involves the initial development of beliefs and evaluations about scientific topics, as for example demonstrated for nanotechnology (C. Lee et al., 2005; D. A. Scheufele & Lewenstein, 2005).

According to Nisbet and Scheufele (2009), such initial exposure serves as a catalyst for the development of new attitudes by making individuals more aware and concerned about scientific issues. As proposed by Holbert and Tchernev (2012), this mode of attitude formation is particularly relevant in the context of science communication because the general public often has limited awareness or understanding of complex scientific issues, as described by the "knowledge deficit model" (Miller, J., D., 1983; Sturgis & Allum, 2004). In this scenario, people may not have pre-existing attitudes toward scientific topics like biotechnology or nanotechnology. Instead, their initial attitudes are shaped by contextual factors and heuristics, such as their trust in science and the credibility of the sources presenting the information, including scientists and business leaders (C. Lee et al., 2005). The source of the message is particularly important in this context, as the credibility, attractiveness, and expertise of the communicator can significantly influence how the message is received and whether it leads to the formation of a new attitude (Hovland et al., 1953).

To gather attitudes in public survey research, either general attitude measures, such as the overall attitude on science are employed (for example "scientific developments make our lives more healthy") or specific attitude measures for technologies or

applications might be used (“new developments in computing lead to more unemployment”) (Bauer et al., 2000). Moreover, the operationalization of attitudes toward science and technology relates to *support* of an issue such as nanotechnology (Gaskell et al., 2005), *perceptions of technological risks and benefits* (Frewer et al., 1998), or with slightly different focus as suggested in the concept of *Public Awareness of Science* (PAS), where positive attitudes toward science and technology were related to *skills and behavioral intentions* (T. W. Burns et al., 2003; J. K. Gilbert et al., 1999).

In the field of science communication, a variety of theoretical models have been developed with the aim to providing a systematic understanding of the historical development of science communication and to plot the evolution of communication modes (for a review see Brossard & Lewenstein, 2009; Trench, 2008). Most concepts can be associated with at least three discrete phases or models of science communication. As Trench (2008) observed, science communication models evolved from an initial emphasis on dissemination (one-way-communication) to a subsequent focus on participation (two-way-communication), which in turn gave rise to models with three-way communication approaches. Nevertheless, existing literature has identified a distinctive focus in the characterization of phases in science communication models. This chapter presents an overview of science communication models and phases, which are grouped into three distinct phases according to the systematic frameworks proposed by Brossard and Lewenstein (2009) and Akin and Scheufele (2017).

As Figure 6 shows, the initial phase of science communication models is concerned with the concept of *scientific literacy*, which emerged in 1960 with the fundamental objective of addressing deficiencies in the general public's scientific knowledge. This model is characterized by a unidirectional flow of communication, with the primary objective being the *dissemination of scientific knowledge* from the scientific community to the general public (Ziman, 1991). Some concepts following the scientific literacy approaches placed greater emphasis on the role of communication contexts (B. E. Wynne, 1992). In this vein, the analytic framework by Brossard and Lewenstein (2009) distinguishes between the knowledge deficit model and the *contextual model*, which underscores the social and individual contexts of communication. This concept underscores the pivotal role of different communication contexts, such as that audiences' attitudes play in shaping the dissemination and reception of emerging technologies within media contexts, thus underscoring the significance of audience-oriented considerations over mere emphasis on knowledge levels (Lewenstein, 2003).

As the second stage of the science communication models indicates, priority is given to audience engagement, which is summarized under the rubric of *Public Engagement with Science (PES)*, or alternatively referred to as *Public Engagement (PE)* (Rowe & Frewer, 2005). This stage is characterized by a dialogue-oriented two-way communication flow involving a diverse range of public actors and scientific stakeholders (S. Miller, 2001; D. A. Scheufele et al., 2021). Subsequently, this mode of science communication models prioritizes audience engagement as public engagement within a dialogue-oriented two-way communication flow that involves a diverse range of public actors and stakeholders (S. Miller, 2001). Moreover, the public engagement (or public participation) model underscores the active involvement of citizens in the policy-making process (Owens, 2000; Stilgoe et al., 2014). One particular variant of this public engagement model is the *lay expertise model*, which emphasizes the interactive nature of scientific communication processes and the importance of engaging local communities (Brossard & Lewenstein, 2009; Lewenstein, 2003).

However, as for example Brossard and Lewenstein (2009) contended, there is a degree of overlap between these science communication models. They assert that the deficit and contextual models seek to disseminate information to the public¹¹, whereas the lay expertise and public engagement models seek to actively engage citizens with science¹². As shown in Figure 6, contemporary science communication methodologies can be broadly classified under the rubric of *participative science communication* models, or the notion of "*collective audiences*", which can be considered as a third phase of science communication models with an emphasis on the diverse needs of these audiences and their active involvement (M. Burns & Medvecky, 2018; Schäfer & Metcalfe, 2021). Akin and Scheufele (2017) referred to these developments as "*communication in context*," emphasizing the involvement of a diverse range of public stakeholders and the heightened significance of digital media complexity to address audiences with unique needs.

Not considered as a specific phase of science communication¹³, but rather as a point of reference especially relevant for this dissertation are science communication

¹¹ Conceptually, however, the contextual model can be placed among models with one-way information transmission (see for example Trench, 2008) and will be outlined in what follows with a focus on the extension to the information dissemination paradigm.

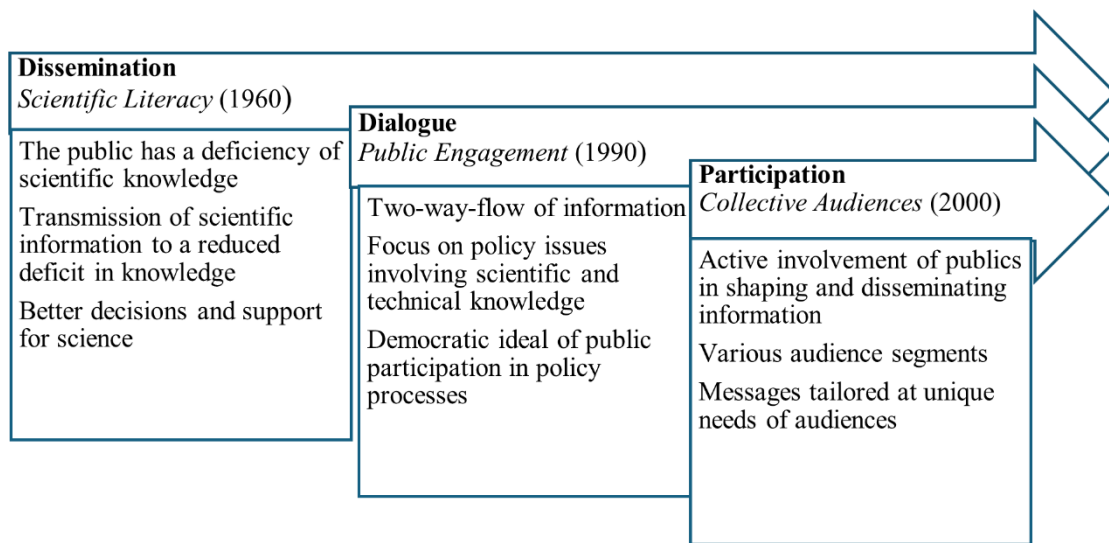
¹² The lay expertise model (see for example Brossard & Lewenstein, 2009) will be the subject of a discussion on approaches to dialogue-oriented models in this chapter.

¹³ However, as proposed in the contextual model (see Brossard & Lewenstein, 2009), differences in the evaluation of science communication content by audiences have been considered from the perspective of information dissemination. Nevertheless, this model has not been extensively specified regarding explanatory variables or effect directions.

effects referring to the perspective of the impact of communication strategies such as framing on attitudes of the audience (National Academies of Sciences, Engineering, and Medicine, 2017; B. Scheufele & Scheufele, 2010). As such, the information citizens rely on about emerging technologies is expected to be mainly converted by the media (D. A. Scheufele & Lewenstein, 2005). Besides more direct effects of the media, it was anticipated that audience variables, such as heuristics and therefore cognitive effects play an essential role in shaping attitudes (S. Chen & Chaiken, 1999; D. A. Scheufele, 2006; Tversky & Kahneman, 1975). These variables, however, were argued to show varying degrees of effectiveness between groups of audiences, such as for different levels of knowledge or information processing capacity (Ho et al., 2008; Nisbet et al., 2002). This perspective of cognitive effects of science communication will be discussed in chapter 4.2.

First, the following section provides an overview of one-way communication approaches, such as scientific literacy and public understanding of science, which will be discussed in the context of the knowledge deficit model. Moreover, the evolution of research on the significance of models that have emerged in response to criticism of the unidirectional relationship between communication and attitude formation will be examined. This will include the identification of concepts that take into account contextual determinants with focus on information dissemination. Subsequently, the premises of the phase of public engagement with science, and thus more dialogical approaches, as well as participative science communication models will be elaborated upon.

Figure 6. Overview on periods and basic assumptions of science communication models and paradigms



Own illustration based on Akin and Scheufele (2017) and Brossard and Lewenstein (2009)

Information Dissemination Models

The initial iteration of the *deficit model* is largely associated with the fundamental premise that public skepticism or opposition to science is a consequence of a deficiency in scientific knowledge (Ziman, 1991). As posited by the *scientific literacy model*, scientists are regarded as authorities on knowledge, while the public is presumed to be deficient in this regard (Miller, J., D., 1983). Therefore, the information flow is characterized as a unidirectional transfer of knowledge from scientists or journalists to the public (see for example Brossard & Lewenstein, 2009). Conversely, a reduction in the perceived knowledge deficit has theoretically been identified as a crucial factor in enhancing support for science. However, empirical evidence supporting this claim is limited (D. A. Scheufele, 2013).

Historically, research on scientific literacy can be traced back to the 1950s (see for an overview for example, Durant, 1994). This research emerged in the context of debates on the increasing scientific development occurring in response to the Cold War and the Soviet launch of Sputnik with the aim to enhance the scientific literacy of the public and provide public support for science (Hurd, 1958). As classified by Durant (1994), scientific literacy can be understood as the belief that individuals in a scientifically and technologically advanced society should possess a specific level of scientific and technical knowledge, encompassing not only the subject matter of science, but also the processes

and social structures associated with it. At the macro level, scientific literacy is linked to a nation's economic prosperity. An adequate level of scientific literacy among the citizenry would ensure the presence of science and scientists, thereby enabling the development of competitive research programs in international markets (Laugksch, 2000). Additionally, enhanced scientific literacy has been proposed as a means of improving the quality and effectiveness of the public decision-making processes (Royal Society, 1985; Thomas & Durant, 1987).

Concurrent with the rise in academic discourse on the societal challenges posed by scientific advancements in the early 1980s, the examination of public attitudes toward science gained prominence in the United Kingdom (Durant et al., 1989). Initially, the deficit model of science communication, which attributes public skepticism toward science to a lack of knowledge, dominated research in the field of *Public Understanding of Science (PUS)* (Smallman, 2014; Sturgis & Allum, 2004). Public Understanding of science can be considered as research paradigm conversely to scientific literacy with focus on the understanding of scientific matters by non-experts, regarding the understanding of scientific facts, and methods with focus on the outreach by the scientific community or related actors (e.g. science writers, museums, event organizers) to the public (House of Lords, 2000).

Public understanding of science approaches emphasized increasing scientific literacy as a way to improve public acceptance of science from the 1960s through the mid-1980s (Bauer, 2009). However, by 1985, a significant paradigm shift occurred, as noted by Bauer (2009). This transition moved the focus from simply educating the public to understanding the complex interplay between knowledge, attitudes, and engagement. Rather than viewing public understanding as merely a question of literacy, researchers began emphasizing the role of public attitudes, trust, and values in shaping responses to scientific issues (Bauer, 2009). A pivotal moment in this shift was the publication of the Royal Society (1985) on public understanding of science. This report emphasized the need to shift from focusing on public awareness to examining public attitudes, leading to the incorporation of social psychological methodologies that enabled researchers to investigate how values and social contexts influence public engagement with science. This evolution in PUS research reflects a broader recognition that science communication must account for societal values and trust dynamics, rather than relying solely on educational interventions (Priest et al., 2003; Weingart & Guenther, 2016).

To gain insight into the context of knowledge surrounding emerging technologies, the *social science and public opinion approach of scientific literacy* can be identified as a relevant avenue of inquiry¹⁴. This approach involves identifying the sources through which individuals obtain scientific and technical information, with the aim of measuring the public's scientific knowledge and attitudes towards science and technology. The attitude toward science and technology in general and toward selected current policy issues in particular has been validated mainly through quantitative surveys. For example, in the United States, survey investigations by the National Science Board (NSB) (1991, 1993, 1996) have provided insights into this matter. Similarly, Eurobarometer surveys have offered valuable data in the European context (Bauer & Schoon, 1993).

In concordance to theoretical discussions, scientific literacy, as well as public understanding of science can be considered a multidimensional construct (see for example Gregory & Miller, 1998 or Laugksch, 2000). One of the earliest empirical definitions of an individual with scientific literacy was developed by Pella et al. (1966). To identify themes related to scientific literacy, the authors conducted a systematic analysis of scientific literature. They concluded that the most significant indicators in the literature were the interrelation of science and society, the ethics, and the nature of science (see Pella et al., 1966). Building upon this early work, Showalter (1974) defined scientific literacy along the lines of seven dimensions that encompass both an understanding of the nature of scientific knowledge, concepts, and theories, as well as the ability to develop skills and to utilize scientific processes to make decisions and interact with the scientific environment.

In his influential conceptual overview on scientific literacy, Miller, J., D. (1983) builds upon the three dimensions of understanding the *scientific approach*, *basic scientific constructs*, and *science policy issues*. According to Miller, J., D. (1998) “the combination of a reasonable level of achievement on each of these three dimensions would reflect a level of understanding and competence to comprehend and follow arguments about science and technology policy matters in the media” (p.205-206). From this conceptualization emerged survey-based indicators of scientific literacy (Miller, J., D., 1983, 1992), which were subsequently utilized in the U.S. Science & Engineering Indicators survey

¹⁴ As Laugksch (2000) reviewed, approaches to scientific literacy differ across research traditions and can be summarized by the interest groups involved in the process. Scientific literacy approaches include formal science education and teaching (Jenkins, 1992), sociological analyses of authority in science education (B. E. Wynne, 1992), and social science approaches examining public support for science and technology policy (Miller, J., D., 1992).

since 1979. With regard to the initial dimension of *scientific understanding*, the NSF survey inquired whether respondents possessed a definitive comprehension of the concept of scientific research, a general understanding of its significance, or a limited grasp of its meaning. In instances where a clear understanding of the term was indicated, respondents were prompted to provide their own definition. The survey yielded results indicating that a substantial 14% of respondents were able to provide an acceptable definition of the meaning of a scientific study (Miller, J., D., 1983). After controlling sociodemographic variables, it was found that individuals with higher levels of formal education demonstrated a greater understanding of the subject matter. It is important to note, however, that only 32% of the sample of respondents with graduate degrees fell into this category (Miller, J., D., 1983).

The second dimension of scientific literacy, as defined by Miller (1983) as *understanding scientific constructs*, was assessed using a self-rating measure, which included questions about the terms radiation, GNP, and DNA. In order to be classified as knowledgeable, respondents were required to demonstrate a clear understanding of at least one of the three constructs and a general awareness of the remaining two. Approximately half of the respondents met this criterion, and there was a strong correlation between formal education and knowledge of scientific constructs (Miller, J., D., 1983). Furthermore, the comprehension of *public science policy issues* was evaluated through the examination of the scientific controversies surrounding three key topics: chemical additives in food, nuclear power, and space exploration (Miller, J., D., 1983). Accordingly, the respondents were requested to identify two potential benefits and two potential harms associated with each of the issues under examination (Miller, J., D., 1983).

In order to be classified as knowledgeable about *science and policy issues*, a respondent was required to identify a minimum of six potential benefits or harms out of a possible twelve (Miller, J., D., 1983). Overall, 41% of the respondents met this criterion, which was positively correlated with the level of respondents' education in other dimensions of scientific literacy. The findings further revealed that scientific literacy was depending on the subject of investigation, respondents exhibited a relatively higher degree of knowledge concerning the benefits and harms associated with food additives and nuclear power, while displaying a comparatively lower level of knowledge regarding the potential adverse effects of space exploration (Miller, J., D., 1983). A single measure was constructed from these three dimensions of scientific literacy, wherein only 7% of individuals qualified as scientifically literate. In light of the empirical scientific illiteracy of

the American public, Miller posited that there are two subsets of the public in terms of science and technology policy formation, which he classified as the "attentive" and the "non-attentive" public (Miller, J., D., 1983).

One significant area of critique of the deficit approach pertains to the operationalization of factual knowledge, which has frequently been employed in surveys based on true or false questions on "textbook items." One illustrative example is the statement, "Electrons are smaller than atoms," which was included in the Eurobarometer 31 survey conducted in 1989 (Durant et al., 1989). In this instance, the number of correct responses to items in the survey was aggregated to yield a total score, which can be argued to oversimplified scientific literacy by emphasizing memorization over a deeper understanding of scientific principles, processes, and societal contexts as proposed in the typology by Miller, J., D. (1983). The research design was also seen as culturally biased, relying on Western-centric educational norms that might not resonate universally, providing the need for culturally sensitive literacy measures (Bauer et al., 2007). Nevertheless, the proportion of the public providing accurate answers to factual questions in surveys has remained consistent over the past 25 years (Miller, J., D., 2004; National Science Board, 2018). Moreover, individual-based factors, such as differences in media information consumption and reception, have not been considered in these scientific literacy approaches. Consequently, the research paradigm of the deficit model has evolved into other concepts that consider the contexts of science communication.

The contextual model of science communication

In light of the critique directed towards the deficit model, there has been a marked development of alternative theoretical approaches (see for example Lewenstein, 2003). One such approach is the *contextual model*, which allows for the role of the communication context of recipients to be considered in terms of their social and cultural environment (Ziman, 1991). In relation to the role of individuals as information receivers, as outlined by Lewenstein (2003), the contextual model challenged the reductionist assumption that public resistance or misunderstanding of science is solely attributable to a lack of knowledge. In contrast, this model underscored that individuals interpret scientific information within the context of their existing knowledge, beliefs, and social environments (Brossard & Lewenstein, 2009).

Therefore, this view considered that individuals receive information within the context of specific messages (Kasperson et al., 1988; Lewenstein, 2003). For example, in

the field of health communication, which has traditionally employed a contextual approach, practitioners and health campaigners adopt the perspective that patients' responses to medical information are shaped not only by the clarity of the information but also by their personal experiences and cultural backgrounds (Lewenstein, 2003). This approach provides insight into how social systems and media representations can amplify or attenuate public concerns about particular issues (Kasperson et al., 1988). In the field of risk communication, the contextual model has been used to elucidate how individuals perceive and respond to risks associated with environmental hazards (Krimsky & Plough, 1988). Furthermore, media coverage of emerging technologies can either accentuate public concerns or diminish potential risks, exerting a considerable influence on public attitudes (Dunwoody & Peters, 1992; Friedman & Egolf, 2005).

Overall, the information dissemination approaches of science communication were argued to be co-opted by marketing and demographic approaches that prioritize achieving public acquiescence for unidirectional communication and persuasion (Lewenstein, 2003), with an absence of feedback over fostering genuine understanding and dialogue rather than as a means of fostering meaningful engagement with the public (Lewenstein, 2003). Consequently, the primary critique of the contextual model pertains to its perceived status as a "more sophisticated version of the deficit model" (Brossard & Lewenstein, 2009). There is a perception that it may implicitly assume that public attitudes should align with those of scientific experts, which could limit its potential for genuine public engagement and understanding (Brossard & Lewenstein, 2009). This has led to demands for a more nuanced understanding of science communication approaches, with a stronger emphasis on the complexities of the science-society relationship (Trench, 2008).

Dialogue-Oriented Approaches

In response to the reviewed critique of knowledge deficit-oriented models, novel dialogue-oriented approaches to science communication have emerged that emphasized the significance of acknowledging local knowledge and facilitated enhanced political inclusion and participation. These approaches, exemplified by public engagement, lay expertise, and public participation models, underscore the social and political dimensions of democratic engagement with science (Einsiedel, 2008; Lewenstein, 2003). This entails public involvement in the decision-making processes pertaining to science and technology in the realm of policy initiatives (see for example Akin & Scheufele, 2017; Macq et

al., 2020). Importantly, the *Public Engagement with Science (PES)* approach, which is sometimes also referred to as *Public Engagement (PE)*, is a concept that emphasizes a two-way flow of information between scientists and the public (Rowe & Frewer, 2005). Ultimately, this approach has gained more widespread acceptance in academic research, as evidenced by the discussion on dialogue and engagement initiatives in Britain (B. E. Wynne, 2006). Despite being used interchangeably with terms like *public outreach* and *public communication* (C. Davis et al., 2022), PES is generally understood as involving processes where scientific knowledge and practices are communicated, debated, and discussed in ways that actively involve the public (Lewenstein, 2003; Trench, 2008). According to Besley et al. (2018), public engagement includes any effort by the scientific community to communicate and interact with people outside of their research areas.

Historically, the discourse around *Public Engagement with Science (PES)* emerged in response to the erosion of public trust in scientific authorities, particularly in the wake of crises such as the 1986 Chernobyl disaster, the BSE (bovine spongiform encephalopathy) crisis (1989-1996), and debates over genetically modified (GM) foods in the late 1990s (Weingart et al., 2021). In the United States, contentious issues like climate change, reproductive technologies, and cloning have served to further challenge public trust (Bensaude Vincent, 2014; Weingart et al., 2021). The conventional approach to communication from policymakers and scientists, characterized by a top-down dissemination of information, frequently served to reinforce skepticism among the general public, who often perceived such communication as dismissive or misleading (Smallman, 2014). These crises, compounded by growing public protests, deepened the disconnect between experts and the public, undermining the legitimacy of both science and government institutions (Weingart, 2023; Weingart et al., 2000). Consequently, there was a notable shift towards more transparent, inclusive, and accountable science communication practices, with the aim of rebuilding public trust and fostering greater engagement with society (Bauer & Jensen, 2011; Rowe & Frewer, 2005).

The development towards participatory models of science communication, which move beyond the limitations of information dissemination models, was recognized through dialogue-oriented approaches that emphasize inclusivity and public engagement (Jasanoff, 2003). In Europe, these developments were formalized through the implementation of policy programs with action plans that sought to inform the public and engage them in discussions about the societal implications of scientific advancements (Weingart et al., 2021). These changes were encapsulated under the framework of *Responsible*

*Research and Innovation (RRI)*¹⁵, which advocates for a transparent, interactive process whereby societal actors and innovators engage mutually in order to ensure the ethical, sustainable, and socially desirable outcomes of innovations (Bucchi, 2004; Conceição et al., 2020).

As Owen et al. (2012) evaluated, the perspective of policy debates represented a progression from the sixth to the seventh EU Framework (European Commission: Directorate-General for Research and Innovation et al., 2012), where the perspective moved away from the view of "*science for society*," which focused on Europe's societal challenges and the notion of a deliberative democracy, towards a stronger emphasis on "*science with society*." This new perspective emphasized the responsibility of research and innovation to be responsive to societal needs and expectations, with institutionalized responsiveness and the linking of research and innovation to responsibility (Owen et al., 2012). From the view of science in society, scientific knowledge production is regarded as a social phenomenon situated within a complex network of political, cultural, and scientific contexts. It manifests in diverse formats and involves a multitude of actors, including the public, and is shaped by a range of procedures pertaining to public involvement and decision-making related to science and technology (European Commission: Directorate-General for Research and Innovation et al., 2012).

Furthermore, the evolution of academic discourse on public engagement was marked by the launch of the *Public Understanding of Science* journal in 1992, which signified a transition from the *Public Understanding of Science (PUS)* model to the *Public Engagement with Science (PES)* model (Nowotny, 2014; Stilgoe et al., 2014). This shift reflected a growing recognition of science as embedded in political and cultural contexts, necessitating the collaboration of a variety of actors, including the scientific community, media, the public, and policy stakeholders (Weingart et al., 2021). Consequently, the concept of public engagement was interpreted as the joint construction of scientific and public knowledge, a process that transcends one-way communication and facilitates an interactive, *two-way dialogue* (Gross, 1994; Smallman, 2014).

The field of *Public Engagement with Science (PES)* has evolved through a variety of theoretical models, with dialogue-oriented approaches gaining prominence as a means of facilitating reciprocal communication between scientists and the public (Trench, 2008). One significant model, the *lay expertise model*, underscores the importance of

¹⁵ See also chapter 2.4 on strategies on the policy implementation of Responsible Research and Innovation (RRI).

incorporating the knowledge of non-scientists into discussions about science (Lewenstein, 2003). This model asserts that communication activities should acknowledge the expertise of communities that are directly affected by scientific and technical issues. A substantial body of research has been dedicated to the utilization of laypersons' insights, predominantly within the framework of case studies (Epstein, 1995), or in the formulation of policies pertaining to subjects such as genetic engineering (Gollust et al., 2005). However, this approach has been met with criticism, as it has been asserted that this practice potentially impedes the ability of experts to address complex or abstract issues effectively (Collins, 2014; B. Wynne, 2004).

As outlined by Brossard and Lewenstein (2009), public engagement with science can occur at varying levels of interaction, involving either a straightforward interaction between citizens and scientific experts, the empowerment of citizens to express their perspectives, or the establishment of genuine public authority over policy. Examples of such engagement include face-to-face communication at public events, media participation, or formal involvement in policymaking (Bauer & Jensen, 2011; Besley et al., 2018). Rowe and Frewer (2005) proposed a threefold typology of public engagement mechanisms. The initial mode to be considered is *public communication*, which involves a one-way flow of information. In this context, information is conveyed from science or governmental agencies to the public. Examples of this communication mode include information broadcasts, such as television programs and printed materials, as well as public meetings (Rowe & Frewer, 2005). The second mechanism of public engagement activities is *public consultation*, which is a two-way flow of information. In this mechanism, members of the public convey information to the sponsors of the initiative, but there is no subsequent process of dialogue. Instead, citizens express their opinions on the topic of interest (Rowe & Frewer, 2005). In this way, the administration of public surveys or focus group studies can be classified as an example of public consultation (Rowe & Frewer, 2005).

Among the most inclusive public engagement activities is public participation, which refers to active involvement in decision-making with the exchange of information between members of the public and the initiators. Typically, this exchange occurs in a group exercise setting and is characterized by a form of dialogue (Rowe & Frewer, 2005). One illustrative example of this approach is the involvement of citizens in consensus conferences, which has been a prominent feature of political and policy discourse in Denmark, France, and the United States since the 1980s (Andersen & Jæger, 1999; Dryzek & Tucker, 2008). Citizen science initiatives, such as the eBird project, which aims to

establish a database of bird populations (Sullivan et al., 2009), and Galaxy Zoo, which classifies images of galaxies taken by telescopes (Raddick et al., 2019), represent significant instances of public engagement in scientific research.

The aforementioned initiatives demonstrate that PES serves not merely as an educational instrument, but also as an exemplar of civic engagement. Active participation in scientific discourse is thus indicative of active citizenship (Bonney et al., 2014). Furthermore, PES facilitates inclusivity by integrating diverse perspectives and fostering trust between the public and scientific institutions (European Commission: Directorate-General for Research and Innovation and Billgren Askwall, C., 2024). For instance, Germany's "Bürgerrat Forschung" (Citizens' Council on Research) engaged citizens in the formulation of recommendations for enhancing public involvement in research policy (Bürgerrat Forschung, 2022). Moreover, the cultural and social context of communication influences the manner by which individuals engage with science, which in turn affects their sense of identity and their role as citizens in a democratic society (Davies & Horst, 2016; B. E. Wynne, 1992). This is for example exemplified by initiatives undertaken by the Biotechnology and Biological Sciences Research Council (BBSRC) in the 1990s, which sought to enhance public confidence through transparency and open debate (Biotechnology and Biological Sciences Research Council [BBSRC], 2025).

Overall, the extant literature on the prevalence and predictors of scientists' public engagement activities suggests that engagement is a common phenomenon (Bauer & Jensen, 2011; C. Davis et al., 2022). For example, a survey of the American Association for the Advancement of Science (AAAS) conducted in 2014 revealed that 48% of scientists reported engaging in at least one outreach activity on a regular basis (Rainie et al., 2015). These activities include communicating with non-experts, participating in media engagements, using social media, or blogging. However, pronounced differences were observed between research disciplines, with social scientists exhibiting the highest levels of public engagement (Rainie et al., 2015). More recent data from the United States indicate that of a sample of 6,242 scientists, nearly all participants engage in some form of science communication (98.3%). Furthermore, 53.2% of the scientists surveyed indicated that they consider public engagement activities to be of high personal relevance (Rose et al., 2020). In contrast, research institutions in Europe exhibit a mixed picture, with many institutions rarely engaging in public outreach, while a few are highly active (Neresini & Bucci, 2010). Moreover, demographic factors have been identified as influential elements in this regard. Senior scientists have been observed to prioritize conventional outreach methods,

whereas their younger counterparts exhibit a propensity to engage more actively on social media platforms (Besley et al., 2013; Crettaz von Roten, 2011). Additionally, gender differences regarding public engagement activities are regarded as minor, with some studies showing higher male participation, while others report greater overall engagement among women (Crettaz von Roten, 2011; Kreimer et al., 2011).

Moreover, attitudinal factors have been identified as a significant determinant of scientists' willingness to engage in public outreach. One of the primary motivators found in empirical research is the aspiration to *democratize* science, thereby empowering citizens to engage in scientific discourse and participate in society (Weingart et al., 2021). Moreover, numerous scientists regard public engagement as a chance to *educate* the public and draw attention to the societal advantages of science, including its part in *promoting innovation* (Besley et al., 2013; Weingart et al., 2021). Another significant motivator is the objective of *legitimizing science* in the public sphere, particularly in the context of combating misinformation (Dudo & Besley, 2016; Weingart et al., 2021). Furthermore, institutional support has been identified as a significant factor influencing scientists' engagement in public outreach. Studies have shown that scientists are more likely to participate in such activities when their institutions actively endorse and facilitate these efforts (Bao et al., 2023). A key component of the Theory of Planned Behavior (TPB) is *efficacy* (Ajzen, 1991), which is also a predictor of public engagement. Internal efficacy, which concerns scientists' own efforts, capacity, or skills in engaging, and external efficacy, which pertains to the belief that their engagement can make an impact, are both pivotal in determining engagement levels (Besley et al., 2018; Besley et al., 2013).

Nonetheless, a number of practical obstacles impede participation, including constraints on time and resources. Additional barriers include a *lack of training and skills*, as well as a general *reluctance towards outreach activities*. Some scientists may also perceive public engagement as having little incentive or may feel discouraged by the *lack of peer involvement* (Dijkstra et al., 2015; Poliakoff & Webb, 2007; Weingart et al., 2021). The self-perception of scientists as communicators is also a significant factor, with those adhering to a deficit model (focusing on informing the public or raising awareness) more likely to engage in science communication (Dudo & Besley, 2016; Wilkinson et al., 2023). As Kessler et al. (2022) illustrated with regard to the motivation of scientists for public outreach in the DACH region, strategic, outcome-oriented communication is often prioritized by early-career academics or those under pressure to secure funding. This aligns with the notion that scientists' views on their role in science communication shape

their actual practices, with older and female scholars typically exhibiting more engagement through the public engagement model (Besley et al., 2013; Crettaz von Roten, 2011).

A close examination of the critique of public engagement with science (PES) reveals several ongoing challenges. PE activities often engage those who are already informed and invested in the topic, which has been argued to create an "echo chamber" (Corley & Scheufele, 2010; Stilgoe et al., 2014). For example, research has shown that individuals with higher education and socioeconomic status have been disproportionately benefited by nanotechnology outreach, while those with lower education have exhibited a decline in knowledge levels over time (Corley & Scheufele, 2010). This lack of inclusivity had been discussed to limit the democratic potential of public engagement with science (Stilgoe et al., 2014; B. E. Wynne, 2006).

Although Public Engagement with Science is frequently regarded as a means of enhancing transparency, legitimacy, and democratic accountability in decision-making processes, its actual impact on policy is often deemed to be limited by critics (Emery et al., 2015; Gregory & Lock, 2008; Weingart et al., 2021). Public engagement initiatives are often conceptualized as instruments for preventing adverse outcomes, including the stigmatization of controversial technologies, unwarranted innovation restrictions, and the establishment of trade barriers (Holdren et al., 2011). Theoretically, effective public engagement with science (PES) can foster public trust and enhance perceptions of the legitimacy of regulatory or policy decisions, particularly when such processes transparently incorporate diverse perspectives (B. E. Wynne, 2006). For example, decision-makers engaging with stakeholders in inclusive and meaningful ways may create the impression that the public's voice is valued, thereby legitimizing outcomes (D. A. Scheufele et al., 2021). Nevertheless, scholars such as Jasanoff (2003) have identified a critical limitation, namely that PES often serves to legitimate predetermined policy decisions rather than genuinely shaping or influencing them. In this view, public consultations can serve as mere symbolic exercises, demonstrating openness to input without significantly altering the direction of governance (Jasanoff, 2003). Such critiques indicate that PES is, at times, more about managing public perception than effecting meaningful change in policy frameworks (Stilgoe et al., 2014). Additionally, it can be argued that the process of science in this participation mode is often prioritized over its substantive content (Lewenstein, 2003).

Consequently, critics have argued that public engagement approaches often fail to deliver on their promises, displaying inconsistency in practice and sometimes producing counterproductive outcomes (Conceição et al., 2020). As Smallman (2014) conducted a content analysis of the most-cited papers in the journal *Public Understanding of Science*, the results indicated that the early enthusiasm for dialogue-based approaches has gradually given way to increasing skepticism. These findings prompt critical inquiries into the efficiency and efficacy of specific instances of public engagement (Smallman, 2014). A mounting body of literature from 2003 to 2010 began to challenge the actual effectiveness of public engagement strategies, suggesting that engagement practices often fail to achieve their intended goals and yield mixed results, thereby obscuring the true impact of public engagement strategies (Smallman, 2014). The evaluation of the effectiveness of PES interventions is frequently grounded in case studies of discrete events or research programs. These case studies tend to focus on elements such as audience demographics, their preferences, and learning outcomes related to their participation in science festivals or public outreach activities (Fogg-Rogers et al., 2015; Grand & Sardo, 2017; A. M. Jensen et al., 2021; Phillips et al., 2018). Predominant methods employed in these studies include surveys, interviews, and observational techniques, which are customized to the unique context of each activity (Grand & Sardo, 2017).

In addition to the challenges associated with evaluation, there are significant issues with measuring PES activities within the context of scientific institutions, academic research, and policy-making (Bauer & Jensen, 2011). The utilization of disparate data sources has been a prominent feature of various studies in this field. These include researcher activity reports (e.g. Impact Unit, 2019; 2023), surveys directed towards scientists or research institutions (e.g. Neresini & Bucchi, 2010; Rose et al., 2020), and interview-based approaches (e.g. Sörensen et al., 2024). The employment of such diverse data sources can give rise to inconsistencies in data quality and the potential for underlying biases, including sampling and social desirability biases (Bauer & Jensen, 2011). Moreover, discrepancies in the definition of populations, such as the inclusion or exclusion of researchers from the social sciences or clinical fields, and variations in measurement tools (e.g., rating scales or activity intensity indicators) complicate cross-study comparisons (Bauer & Jensen, 2011). To enhance the consistency and reliability of PES studies, some scholars propose that the field should standardize critical elements, including definitions of PES activities, sampling methods, and intensity indicators, as well as adopt universally

accepted measurement and evaluation standards (Bauer & Jensen, 2011; Rowe et al., 2005).

Notwithstanding the critiques mentioned above, the significance of public engagement in the sphere of science communication remains indisputable (Brossard & Lewenstein, 2009). This component has influenced subsequent audience-centered approaches (Holford et al., 2023), which prioritize interactions with the public and foster the policy context of the co-creation of knowledge (Matti et al., 2022). In particular, audience-oriented models place emphasis not only on the transmission of scientific information but also on what has been termed the 'social conversation around science' (Akin & Scheufele, 2017), which encompasses the fostering of mutual understanding, dialogue, and active participation (Bucchi & Trench, 2021). Therefore, while PES has been the subject of legitimate criticism, it has undoubtedly influenced the development of even more inclusive and interactive conceptualizations of science communication.

Participatory approaches

Since the 1980s, there has been a notable shift in the field of science communication, with a growing emphasis on audience-centered approaches that build upon and refine earlier public engagement frameworks (Livingstone, 2003). While public engagement approaches focus on the involvement of the public in scientific discussions and decision-making processes, they often view the public as a relatively unified entity that interacts with science in a general sense, emphasizing participation and inclusion (Brossard & Lewenstein, 2009; Trench, 2008). In contrast, audience-centered approaches adopt a more sophisticated understanding of the public, recognizing its diversity and complexity. Instead of assuming a homogeneous public, this perspective emphasizes the concept of 'collective audiences' (Holford et al., 2023). Moreover, it acknowledges the existence of multiple and discrete social groups, each with varying degrees of interest, knowledge, cultural backgrounds, and engagement with scientific issues (Akin & Scheufele, 2017; Bucchi & Trench, 2021).

Notably, the distinction between these two approaches lies in the level of detail and precision of the interaction. The prevailing consensus among public engagement frameworks is that the implementation of comprehensive mechanisms is imperative to facilitate the integration of science and society (Rowe & Frewer, 2005). These frameworks emphasize the utilization of deliberation, consultation, or co-creation processes with an undifferentiated public (Bucchi & Trench, 2021; Matti et al., 2022). Conversely,

collective audience models enhance this by adapting communication strategies to address specific audience characteristics, needs, and preferences. For instance, the *participatory model* (see for example Bucchi & Trench, 2021) inherent in collective audience approaches emphasizes "*knowledge co-production*," whereby scientists and specific public groups collaborate based on mutual expertise and shared interests (Holford et al., 2023; Metcalfe, 2019).

In an era marked by rapid technological advancements and fragmented media environments, audience-centered models address the challenges of communicating with specialized, polarized, or niche groups rather than relying on the broad, mass-audience assumptions of earlier public engagement paradigms (Schäfer & Metcalfe, 2021). Such an approach has been described to allowing science communication to better navigate the complexities of societal values, cultural differences, and technological change, ensuring that efforts to build trust, collaboration, and understanding are not only inclusive but also strategically targeted (Akin & Scheufele, 2017). In response to these shifts, global programs have intensified their focus on promoting public awareness of science (European Commission, 2011), offering communication training for scientists (Silva & Bultitude, 2009), and an increasing number of universities and research institutions are integrating science communication theory into their curricula and research initiatives (Fährnich et al., 2021).

The concept of "post-normal science" emphasizes the uncertain societal consequences of contemporary research, advocating for regulation that assesses risks and benefits while ensuring informed science journalism, particularly for ethically contested issues like CRISPR gene editing (Brossard et al., 2019; D. A. Scheufele et al., 2021; Turnpenny et al., 2010). As Roco and Bainbridge (2002) described in the case of NBIC technologies, these fields rely on fundamental units — atoms, genes, information bits, and neuronal synapses — and span multiple scales of complexity, fostering interconnected systems that drive technological innovation and societal progress. These technologies exemplify a collaborative approach to knowledge creation, uniting previously distinct scientific fields to generate transformative opportunities across sectors (Winickoff et al., 2021). However, the rapid expansion of these technologies is accompanied by an increase in ethical and social concerns, which underscores the necessity for public involvement in decision-making processes and discourse that address these broader implications (European Commission, 2022; European Commission: Directorate-General for Research and Innovation & Schomberg, 2011).

Concurrently, shifts in media systems since the 1990s have had a profound impact on the dissemination of scientific information (Brossard et al., 2019; Bubela et al., 2009). The prominence of traditional journalism has diminished as a result of economic pressures, with digital platforms assuming a dominant position in the modern media landscape (Badenschier & Wormer, 2012; Schäfer, 2017). Recent economic shifts within the media sector have given rise to the emergence of new actors in the evolving media landscape; these actors have been conceptualized within the theoretical framework of mediatization (Kepplinger, 2002). Due to the advent of social media platforms such as Twitter and Facebook, novel avenues for public engagement between scientists, research institutions, and policymakers have emerged (Anderson et al., 2010; Davies & Hara, 2017). Additionally, the emergence of digital media has contributed to the fragmentation of audiences, marking a shift from the era of mass communication to one where interest-specific content is developed for specialized science communication audiences (Schäfer et al., 2018; Schäfer & Metcalfe, 2021).

Recent advancements in digital technology have led to a paradigm shift in the manner in which audiences are segmented, thereby presenting both opportunities and challenges to the realm of science communication (Schäfer & Metcalfe, 2021). While digital platforms enable personalized outreach, they also increase the risk of echo chambers and misinformation (Brossard et al., 2019; Fährnrich, 2021). As Riesch, H. et al. (2013) have observed, conceptions of science communication have evolved from a focus on comprehension to engagement, and most recently, to a "third mode" of engagement. This shift has led to a greater involvement of multiple stakeholders in science communication, highlighting interactive engagement (A. Petersen et al., 2009).

Moreover, the digital revolution has transformed the role of audiences in the science communication ecosystem, shifting the dynamic from a passive consumption of information to an increasingly active audience (Livingstone, 2003). Social media and online platforms have provided users with spaces in which they are not only consumers of scientific content, but also are selective in their content choices, engage in meaningful interactions, including discussions, sharing of information, and even the production of content (Su et al., 2015). These platforms facilitate dynamic, reciprocal interactions, dismantling the conventional barriers between scientific communities and the public (H. P. Peters et al., 2014). Digital media have introduced innovative and diverse forms of engagement that were previously unattainable and the provision of interactive features, including comment sections, live Q&A sessions, and user-generated content, enables individuals to

engage with science communication in more participatory and impactful ways (H. Chen et al., 2021; Manosevitch & Tenenboim, 2017). In conclusion, these developments may require a refinement of science communication frameworks to adapt to the increasing decentralization and democratization of information dissemination (Akin & Scheufele, 2017).

Conceptualizations of science communication audiences

Digital media platforms have further transformed audience dynamics by enabling greater interactivity and participation (Livingstone, 2003). These platforms provide users with the opportunity to actively engage with content, participate in discussions, and co-create knowledge (Bubela et al., 2009). This shift requires a reassessment of science communication strategies, with an emphasis on the significance of *multidirectional dialogue* and the *co-production of knowledge* among scientists, policymakers, and the public (Einsiedel & Thorne, 1999; Macq et al., 2020). However, these opportunities are not without challenges. For example, selective exposure of information (Jang, 2013) and the fragmentation of audiences into smaller, like-minded groups (Bright, 2018) can result in the formation of “echo chambers” (Flaxman et al., 2016), particularly in the context of controversial technologies such as genetically modified crops (Byrne et al., 2002) or genomics (Bos et al., 2010). The user segment that indicates the Internet as their primary source of science and technology news can be considered as diverse in age, predominantly male, and more formally educated and knowledgeable about science and technology (Anderson et al., 2010). Research indicated that science communicators face the challenge of addressing diverse audience preferences and leveraging multiple communication channels, with the objective of tailoring messages to resonate with various audience segments (Nisbet et al., 2002; Stocklmayer, 2001). In consequence of these complex developments, *networked publics models* and *participatory communication approaches* emerged (Boyd, 2010; Holford et al., 2023).

However, the concept of “audiences” in the context of science communication is often not clearly defined, with implicit assumptions taking precedence over explicit definitions (Bucchi & Trench, 2021). These conceptions vary significantly, oscillating between perspectives of general, ‘mass’ audiences and more specialized groups (Schäfer & Metcalfe, 2021), as well as between more passive and active roles of audiences (McCarthy & Grant, 2024). Additionally, distinctions can be drawn between local and geographically dispersed audiences (Schäfer et al., 2018), or between individualized and collective

audience formations (Holford et al., 2023). As previously discussed, this lack of clarity is further compounded by the assertion that there have been changes in the practices of science communication (Fahy & Nisbet, 2011). These shifts further involve changes in the composition, expectations, and engagement levels of audiences, reflecting broader transformations in communication technologies, societal dynamics, and public attitudes toward science (Davies & Hara, 2017; D. A. Scheufele & Krause, 2019). As previously stated in literature reviews, a more nuanced and explicit approach to defining and studying audiences could enable the development of communication strategies that are better tailored to address the diverse needs and contexts of different audiences (H. P. Peters et al., 2014; Schäfer et al., 2020).

Furthermore, the evolving understanding of audiences in *communication science* provides a comprehensive framework for refining approaches to science communication, particularly in the context of *digital transformation* (H. P. Peters et al., 2014) and *audience segmentation* (Schäfer et al., 2018). It is not the purpose of this section to provide a comprehensive account of contemporary audience theory in communication science (see on this matter for example McQuail, 1997). However, it is important to note for the context of digital science communication that audiences are not passive recipients of messages; rather, they are active participants who interact with, interpret, and sometimes reshape the messages they encounter (McQuail, 1997). From the perspective of audience theory, the shift from traditional unidirectional communication models to multidirectional, interactive models reflects the broader transition in media landscapes (Brossard, 2013). The notion of audiences as homogeneous, passive entities, a perspective that can for example be observed in the Shannon and Weaver (1949) model, has been replaced by conceptualizations that emphasize *segmentation*, *diversification*, and *interactivity* (McQuail, 1997).

A more active role of the audience is of particular significance in the context of science communication, where the intricacies of scientific content necessitate the implementation of bespoke strategies that engage with diverse audience segments, who may possess varying interests, levels of literacy, and values (Akin & Scheufele, 2017; Longnecker, 2023). Accordingly, the study of *selective exposure* to media (Stroud, 2010; Zillmann & Bryant, 1985) examines how messages are interpreted by audiences in diverse ways based on their preexisting attitudes. For example, participants might end up to choose science information that is consistent with their viewpoint and therefore

represent confirmation bias in attitude formation (Knobloch-Westerwick et al., 2017; Sude & Westerwick, 2022).

In the context of science communication, this is reflected in the shift towards *collective audience approaches*, whereby communication is tailored to specific audience groups, defined by their distinctive characteristics and needs (Brossard, 2013; Metcalfe, 2019). Herein, the focus is on the *values* and *beliefs* held by the audience, *attitudes* such as awareness, understanding, and skill development, and behavioral change (Longnecker, 2023). Early conceptions of different engaged publics can be traced back to Miller (1997; 1992) who introduced the terms “*attentive*” and “*interested*” to describe publics with relatively high levels of scientific literacy. In contrast, audiences lacking interest in science communication have been characterized as “*disengaged*” (M. Burns & Medvecky, 2018; Schäfer et al., 2018). Wynne's (2007) concepts of *invited* and *uninvited* publics differentiate between groups formally included in institutional science communication (invited publics) and those who engage independently or critically without institutional invitation (uninvited publics). The distinction thus draws attention to the inherent power dynamics at play in public engagement, underscoring the imperative for inclusivity and the necessity of facilitating the articulation of dissenting voices rather than attempting to foster a narrow and controlled consensus (B. E. Wynne, 2007).

With a distinct focus, Longnecker (2023) distinguished between three categories of audience: those who are interested or appreciative, those who are uninterested, and those who are *skeptical* or *polarized*. The latter is also described by Schäfer et al. (2018) as “critically Interested,” which conveys to a strong interest and support for science but with less trust in it. Additionally, they refer to “passive supporters,” who exhibit moderate levels of interest, trust, knowledge and tempered perceptions of science. However, there is evidence to suggest that audience conceptions are not necessarily stable over time. Indeed, a considerable amount of research indicates that audiences may change from one segment (i.e., the more critical) to another (Klinger et al., 2022).

In sum, audiences can be regarded as a continuously evolving collective in social settings (Jasanoff, 2014). Therefore, the distinction of *issue-oriented publics* has been drawn to “civic epistemologies” (Jasanoff, 2005) in terms of knowledge production, as such, different audience segments have different views on social implications of science and society. In the context of technology, Nisbet and Markowitz (2014) have demonstrated that individuals who exhibited high scientific optimism and low reservation about science were three times more likely to support embryonic stem cell research than those

who expressed scientific pessimism and high reservation. Furthermore, individuals who expressed low scientific optimism and high scientific reservation were identified as disengaged and showed moderate support for stem cell research. With regard to energy-saving behavior, an analysis by Sütterlin et al. (2011) revealed that audiences exhibit distinct motivational profiles. As such, idealistic energy-savers are highly engaged and driven by sustainability values, whereas selfless inconsequent savers make significant efforts but lack consistency (Sütterlin et al., 2011). Those who prioritize financial benefits over environmental concerns may be described as "thrifty savers," whereas those who focus on cost-driven actions and prioritize environmental concerns as "materialistic consumers" (Sütterlin et al., 2011). Furthermore, convenience-oriented indifferent consumers are the least engaged group, prioritizing comfort over energy conservation (Sütterlin et al., 2011). In addition, consumers who are problem-aware of environmental issues and prioritize well-being tend to recognize the importance of energy conservation but may not perceive a personal obligation to take action (Sütterlin et al., 2011).

However, these segmentation analyses on public perceptions and attitudes toward scientific and environmental issues exhibit several limitations. As for example Metcalfe and Schäfer (2018) concluded, numerous studies are characterized by a lack of comparative perspectives, showcasing varying degrees of topical focus and geographic coverage. A majority of these studies are centered on Western nations, thereby lacking cross-national comparisons. Nonetheless, this oversight often failed to consider the multifaceted impact of media across various demographics, including age, gender, and educational levels (Nisbet et al., 2002).

Summary of science communication models and implications

Science communication's original emphasis on deficit-oriented models and unidirectional information dissemination has been a subject of considerable debate (see Miller, J., D., 1983). Instead, there is a growing interest in more dialogue oriented approaches, such as public understanding of science, and participative approaches with highlighting active participation of audiences (see for an overview for example Brossard & Lewenstein, 2009; Trench, 2008). The application of these models underscores the necessity for adaptability in science communication, as diverse contexts — emerging technologies, environmental concerns, or public health emergencies — may necessitate distinct communication strategies (see for example Einsiedel, 2008; Entradas et al., 2020).

However, the distinct perspectives and phases of science communication are seen as more dynamic in recent discussions and as facilitating more tailored communication that resonates with specific audiences, rather than a “one-size-fits-all” model (Brossard & Lewenstein, 2009). Thus, the coexistence of these models highlights the flexibility needed in science communication, as different contexts may require different communication approaches (see for example Einsiedel, 2008; Entradas et al., 2020).

In some cases, the deficit model is necessary for quickly informing the public, while in others, dialogue or participatory models better address complex societal concerns. In several case-studies, illustrating different contexts and modes of science communication, Brossard and Lewenstein (2009) concluded that the general goal of science communication is to communicating accurate scientific information to an audience, regardless of the extent of audience engagement involved in some projects. Bucchi and Trench (2021) proposed a framework for the *social conversation around science* to capture these divergent science communication perspectives and assumptions which they consider to be leaning against science communication models. As shown in Table 1, the orientations of communication actions and conversations around science might be more or less open or closed, with lesser or greater emphasis on purposes of communication in less or more formal settings (Bucchi & Trench, 2021). This dynamic has the potential to give rise to novel formats of science communication. Depending on the communication mode, these formats can emerge, either to assert towards more participation, but also in the direction of claiming scientific legacy, for example during the ongoing global health crisis, or foster greater participation (Bucchi & Trench, 2021).

Dissemination approaches

As elaborated on in this chapter, the *dissemination* perspective of science communication reflects the paradigm of scientific literacy which emerged in the 1960s, where a *knowledge deficit* towards science in the public was assumed (Laugksch, 2000; Miller, J., D., 1998). The social perspective of *scientism* underlines that science holds the authority on knowledge (Peels, 2023; Welsh & Wynne, 2013). Thus, communication is seen as a linear, one-way transmission of information from scientists to the public. This perspective posits that the public’s lack of scientific knowledge can be remedied by simply providing information, which in turn is expected to lead to more informed decisions and greater public support for science (Miller, J., D., 1983; Ziman, 1991). As illustrated in Table 1, these assumptions of science dissemination to the public can be drawn around different

communication modalities. The *defense* perspective suggests that the public is hostile on science, while they should be informed about science, which can also be related to the aim of combatting misinformation (D. A. Scheufele & Krause, 2019), and a technoscience perspective emerges, wherein science and technology are intricately linked and coproduced (Latour, 1987). As a result, communication is conceptualized as a linear, unidirectional transmission of information from scientists to the public (Sturgis & Allum, 2004). Conversely, proponents of this perspective posit that the public's perceived lack of scientific knowledge can be addressed by the mere dissemination of information, which is expected to result in more informed decision-making and heightened public support for science (Miller, J., D., 1983; Ziman, 1991).

Science communication can have a *promotion* function in the sense of a marketing perspective to persuade the public as of means to excite the public about and increase their appreciation and support for science (Trench, 2008). The popularization of science serves the fundamental purpose of informing the public and making scientific content accessible by "translating" complex scientific language into a comprehensible form (Dunwoody & Peters, 1992; Willoughby et al., 2020), for example by adopting scientific facts on nanotechnology for the audience in newspaper contexts (Faber, 2006). *Outreach* is a modality of science communication that can take various forms, including one-way activities such as government agencies disseminating scientific information through social media to audiences (N. M. Lee & VanDyke, 2015). Nonetheless, this communication mode can also be situated within a more dialogic paradigm. The implementation of public engagement with science as "public communication" (Rowe & Frewer, 2005) serves the purpose of informing and educating the public, thereby promoting public awareness and acceptance of emerging technologies and improving the legitimacy of policy decisions (D. A. Scheufele et al., 2021).

One of the most salient criticisms leveled at the knowledge deficit perspective is its oversimplification of the communication process by treating the public as a homogeneous group. Specifically, a central point of debate among researchers is the perceived failure of the aforementioned model to adequately account for the wide array of values, experiences, and backgrounds that are characteristic of the individual (see for example Bauer et al., 2007; D. A. Scheufele et al., 2021). During the 1970s, the *contextual model* underwent an expansion in its scope, acknowledging the necessity of accounting for particular audiences and the broader social and cultural contexts in which communication takes place (Lewenstein, 2003; Ziman, 1991). In the context of media reporting, the model

finds applicability in the realm of benefit and risk reporting, and its influence on audience attitudes, such as support and risk perceptions of technology (Dunwoody & Peters, 1992; Friedman & Egolf, 2005). However, the contextual model remained reliant on a unidirectional flow of communication, lacking opportunities for feedback, thereby constraining its capacity to engage the public in a more profound manner (Brossard & Lewenstein, 2009).

Dialogue approaches

By the 1990s, approaches to *Public Engagement with Science* (PES) had started to gain traction, advocating for a two-way flow of information between scientists, policymakers, and the public (Rowe & Frewer, 2005). Herein, the *science in society* perspective highlights the imperative to consider knowledge production and research and innovation as a social phenomenon situated within a complex network of political, cultural, and scientific contexts (Owen et al., 2012). Consequently, policy frameworks and initiatives have been developed that prioritized public involvement and dialogue (European Commission: Directorate-General for Research and Innovation et al., 2012). As such, dialogue-oriented science communication approaches prioritize scientific issues, while the advent of emerging technologies can be regarded as a matter of "post-normal" science, characterized by uncertainties in knowledge production and ethics (Funtowicz & Ravetz, 1994). These broad societal transitions are also reflected in post-academic science, as described by Ziman (1996) with research funding increasingly stemming from governments, industries, and private organizations that demand measurable outcomes and practical applications. In alignment with the concept of "Mode 2 knowledge production," research is problem-driven, context-sensitive, and transdisciplinary, contrasting with the curiosity-driven and discipline-focused approach of traditional Mode 1 science (Ziman, 1996).

In the dialogue-oriented mode of *consultation*, members of the public are involved in research projects, such as surveys, to express their opinions on the topic of interest (Rowe & Frewer, 2005). As articulated under the framework of *Responsible Research and Innovation (RRI)*, interactivity is considered a process that engages scientific and societal actors to ensure that the outcomes of innovations are ethical, sustainable, and desirable from a societal perspective (Bucchi, 2004; Conceição et al., 2020). Participation and discussion of scientific topics within local communities exemplifies this interactivity, for example by participating and discussing scientific issues in local communities (Brossard & Lewenstein, 2009). Furthermore, the act of *deliberation* may be conducted

in settings where a diverse range of stakeholders are engaged in democratically structured processes to deliberate upon scientific issues, such as town hall meetings. Such a deliberative approach may encompass either the discussion of scientific issues or the collaborative creation of *knowledge* (OECD, 2022; World Economic Forum, 2019).

Participatory approaches

Science communication, from a *participatory perspective*, is centered on the processes of interpreting and (re-)constructing knowledge (Bucchi & Trench, 2021), which was stressed by the *society in science perspective* (Matti et al., 2022). Active participation in the scientific discourse can also be considered as indicative of civic citizenship (Bonney et al., 2014). Citizen science projects have been shown to influence public knowledge and attitudes through the involvement of volunteers in the scientific process (Brossard et al., 2005) and have also demonstrated broad applicability in various research areas (Phillips et al., 2018; Sullivan et al., 2009). Additionally, open formats in informal settings such as science cafés (Childers et al., 2022), science centers and museums (Hendricks & Donofrio, 2024), and art-research collaborations (NCCPE, n.d.) have been identified as effective conduits for civic engagement.

These participatory approaches have underscored the significance of engaging the public in policy deliberations concerning scientific matters, aligning with democratic principles of participation (European Commission: Directorate-General for Research and Innovation and Billgren Askwall, C., 2024). Despite their strengths, such initiatives have been argued to reach only those already interested in science, thereby limiting their impact on broader audiences and policymaking (Smallman, 2014). However, recent discourse has emphasized the value of recognizing the distinct phases and perspectives inherent in science communication (Akin & Scheufele, 2017; Bucchi & Trench, 2021). In order to address the recent societal challenges, such as the fragmentation of information environments, it is imperative to consider science communication processes from the *audience's perspective*, as several authors have underscored (Longnecker, 2023; Schäfer & Metcalfe, 2021). By placing greater emphasis on the perspective of the audience and audience engagement, science communication can become more targeted and effective, catering to the varied addressing the diverse needs and preferences of various public groups (Bucchi & Trench, 2021).

Table 1. Science communication framework of the social conversation around science

	<i>Modalities</i>	<i>Aspects of science</i>	<i>Social perspectives</i>	<i>Public responses</i>	<i>Orienta- tion</i>
Dissemina- tion	Deficit	Findings: fi- nished know- ledge	Science lite- racy Scientism Technocracy	Information	Purposive
	Defence			Awareness	Hierarchical
	Promotion			Learning	Formal
	Popularization				
	Outreach				
Dialogue	Engagement	Issues: appli- cations and implications of knowledge	Science in so- ciety Post-normal Post-academic	Questioning	
	Consultation			Opinion	
	Interactivity			Discussion	
Participation	Deliberation	Processes: in- terpreting and (re-) con- structing knowledge	Society in Sci- ence Civic science Citizen science	Sharing	Non-purpos- ive
	Chat			Creating	Participatory
	Play			Critique	Informal
	Co-creation				
	Film & Fiction				
	Art- science				

Own illustration based on Bucchi and Trench (2021)

3. Theoretical Perspectives on Attitude Formation

A comprehensive understanding of the underlying mechanisms of attitude formation is of critical importance to policymakers, scientists, and communicators alike (Bauer et al., 2000; Ho et al., 2010). The formation of public attitudes toward science and technology has been discussed as a process influenced by a multitude of variables (Allum et al., 2008; C. Lee et al., 2005). For example, D. A. Scheufele and Lewenstein (2005) have asserted that attitudes towards the subject area of emerging technologies are "a function of a variety of sometimes competing and other times complementary influences, including socio-demographics, personal ideologies, risk–benefit perceptions, prior knowledge, and media framing" (p. 1). Consequently, the multifaceted relationship between the information on emerging technologies received by the media, the contextual environment, and the pre-dispositions of the audience renders the determination of the direction of effects challenging (Nisbet et al., 2002). For instance, this complexity arises when recipients evaluate the risks and benefits of a technology that has been demonstrated to be associated with their existing attitudes toward it (e.g., Binder et al., 2011; Gaskell et al., 2004).

The initial step in this investigation is to establish a conceptual framework for understanding attitude and its formation (3.1). Chapter 3.1.1 explores the theoretical underpinnings of attitude and the process of attitude formation, drawing upon the insights of psychological perspectives on cognitive attitude formation. Chapter 3.1.2 further evaluates the relationship between the variables of attitude and behavior by employing behavior change theories. Subsequently, in chapter 3.2, the theoretical underpinnings of persuasion are explored, with an evaluation of information processing models (3.2.1) and the determinants of attitude formation (3.2.2). Additionally, chapter 3.2 delves into the theoretical foundations of resistance to persuasion (3.2.3). By integrating the theoretical models and determinants of persuasion, chapter 3.3 discusses the significance of attitude formation for this dissertation with regard to effects of science news reporting and its determinants.

3.1 Conceptualizing Attitude Formation

As summarized in the functional approach to attitudes by Katz (1960) "the conditions under which public opinion develops is to be found in the attitudes of individuals, whether they be followers or leaders and whether these attitudes be at the general level of tendencies to conform to legitimate authority or majority opinion or at the specific level of favoring or opposing the particular aspects of the issue under consideration" (p.163). In the

domain of science communication, a comprehensive understanding of attitude formation is essential for the development of effective messages that can influence *public perceptions*. Moreover, Nisbet and Scheufele (2009) constated that science communication efforts “need to be based on a systematic empirical understanding of an intended audience's existing values, knowledge, and attitudes, their interpersonal and social contexts, and their preferred media sources and communication channels” (p.1767). The collective effect of these factors can be encapsulated within the broader concept of *public perception or attitude towards science and technology*. This perception is influenced by the dynamics of media reporting, societal discourse, and cultural narratives (Bauer, 2005; Cobb & Macoubrie, 2004; Joubert et al., 2020). *Public attitudes toward science* (sometimes also referred to as Public Acceptance of Science, see, for example, Mielby et al., 2013) are particular relevant within the frameworks of *deficit-oriented public perception* (Miller, J., D., 1983; Sturgis & Allum, 2004), indicating that the public generally lacks well-defined attitudes toward scientific issues due to limited or inadequate understanding. In the field of science communication, attitudes toward science have been linked to the public's evaluation of societal outcomes resulting from science and technology¹⁶ (Bauer et al., 2000; Miller, J., D., 1983).

3.1.1 Defining Attitudes and Attitude Formation

As a broad construct employed in the field of social psychology, *attitude* can be narrowed down to form evaluative judgments (see, for example Eagly & Chaiken, 1993; Fazio, 2007), as "a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor" (Eagly & Chaiken, 1993, p. 1). In this definition the key elements of investigation are evaluation, the attitude object, and tendency (Eagly & Chaiken, 1993). Attitude objects are defined as specific and direct entities that elicit evaluative responses, thereby distinguishing attitudes from broader constructs such as moods (Eagly & Chaiken, 2007). These objects can be abstract, for example in the case of liberalism, concrete for example referring to the White House, individual (e.g., a person), or collective (such as referring to a group) (Eagly & Chaiken, 2007). Stimuli, such as a person's image, actions, or media portrayal, trigger these evaluations (Eagly &

¹⁶ As Bauer et al. (2000) have noted, scientists are compelled to distinguish science from technology, yet the public often conflates the two, perceiving science through its applications in healthcare or products. Science policy encompasses the convergence of science, technology, and industry into "technoscience." However, it can be argued that science's fundamental principles extend beyond mere practical utility, a distinction that merits preservation in certain contexts.

Chaiken, 2007). Eagly and Chaiken's (1993) proposal to prefer the term "tendency" over "state" or "disposition" is anchored in the notion that it sidesteps the implications of temporality, thereby allowing for a more nuanced examination of attitudes.¹⁷ Therefore, attitudes are distinct from opinions. For example, Katz (1960) underscored the difference between opinion, defined as the verbal expression of an attitude, and attitude, which can also manifest in nonverbal behavior. However, as suggested in the related literature, global evaluations or attitudes can be based on several factors, such as emotions, beliefs, or past experiences and behaviors (Breckler, 1984; Petty & Wegener, 1998a).

Attitudes generally serve several functions that help individuals navigate life (see for example Perloff, 2023). Reasons for the maintenance or alteration of attitudes for individuals based on their motivational function have been identified by Katz (1960) in his functional approach as adjustment, ego defense, value expression, and knowledge. The *adjustive, instrumental or utilitarian function* of attitude (see for example the behavioristic learning theory by Skinner, 1963) is based on the utility of an attitudinal object in need satisfaction and proposes that people pursue to maximize rewards and avoid punishments (Katz, 1960). Furthermore, the *ego defense* function of attitude describes individuals to protect against internal conflicts and external dangers, thereby reducing their anxieties created by such problems (Katz, 1960; Katz et al., 1956). Ego-defensive attitudes frequently rely on defense mechanisms, such as denial, rationalization, projection, and displacement, which distort reality to shield the individual from uncomfortable truths and to defend the self-image (Katz, 1960).

According to the *value-expression function* of attitudes, people derive intrinsic satisfaction when their attitudes mirror their deeply held beliefs and self-concept. Through these attitudes, individuals communicate their identity to others while concurrently maintaining self-identity, thereby enhancing a favorable self-image and self-determination (Katz, 1960). This process is shaped during the early stages of life by socialization and continues as individuals join new groups, where aligning with shared values further reinforces their personal identity (Katz, 1960). Based on the *knowledge function* of attitudes, individuals require orientation and stability to understand the world. Drawing on cultural norms and pre-existing stereotypes, they interpret events that directly impact their lives (Katz, 1960; Lippmann, 1922).

¹⁷ The view of attitude as a latent tendency to respond to a psychological object has also been reflected by Fishbein and Ajzen (2009).

A substantial body of research has been dedicated to the conceptualization of attitudes as a multidimensional construct, which is organized based on the *three-component model* of attitude in affective, cognitive, and behavioral aspects (see for example Katz, 1960; Ostrom, 1969; M. J. Rosenberg & Hovland, 1960). Regarding how attitudes are formed, the *affective component* relates to the emotional responses individuals have toward an attitude object or the intensity of their feelings for or against a social object (Katz, 1960). As such, affect refers to the positive or negative feelings and emotions that an individual associates with an attitude object (Katz, 1960). Research such as Zajonc's (1980, 1984) work on the "mere exposure effect" has shown in this regard how repeated exposure can produce affective responses and strengthen attitudes. Additionally, as Krosnick et al. (1992) have shown that briefly viewing images of unfamiliar individuals, presented with either positive or negative subliminal depictions, can influence attitude formation. Notably, the results of respective studies have indicated that positive images, such as kittens or a wedding, led to more favorable ratings of the unfamiliar person, while negative images, like snakes or a bloody shark, led to more negative evaluations (Krosnick et al., 1992).

According to Katz (1960), the *cognitive component* of attitude (also referred to as belief, see Katz, 1960) denotes to the specificity or generality of the attitude and the degree of differentiation of the beliefs. In the context of attitude change, the predominant cognitive process is elaboration (Petty & Cacioppo, 1981, 1986a), which was defined as the degree of thinking about an attitude object's attributes (Petty et al., 1995). Dual-process-models of attitude formation such as the Elaboration Likelihood Model (ELM) and Heuristic-Systematic Model (HSM) have sought to identify the processes by which individuals process information related to an attitude object, either central (systematic) or peripheral (heuristic) processing of information resulting in attitude change (Chaiken, 1980; Petty & Cacioppo, 1986b).

Furthermore, the *behavioral dimension* of attitudes signifies the manner in which attitudes influence and predict individual behavior (Katz, 1960). Fishbein and Ajzen (1975) highlighted that the greater the alignment between an individual's attitude and their behavior, the stronger the correlation between the two. The factors that influence voluntary actions have been encompassed in theories on behavior change, especially Ajzen's Theory of Reasoned Action (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991). Three basic determinants of behavior have been identified: attitudes toward the behavior, normative beliefs, and motivation to

comply with norms (Ajzen, 1991; Fishbein, 1967; O'Keefe, 2002). It is noteworthy that behavior change theories and information processing theories can be regarded as complementary frameworks in the domain of persuasion research, with each addressing different yet interconnected aspects of attitude and behavior modification (Cappella, 2006). However, it can be argued that the integration of both approaches in the study of persuasion enables the development of strategic and effective message designing, while behavior change theories identify the beliefs and pathways necessary for persuasion, information processing theories enhance message effectiveness by explaining how audiences engage with and process persuasive content (Cappella, 2006). Yet, integrative models, such as the MODE model by Fazio (1990; 1986), have been developed to specify cognitive processes underlying the expectancy-value based attitude and behavior relationship.

Overall, the three-component-attitude model has received empirical evidence that supports its theoretical dimensions of attitude (for example Breckler, 1984). However, some scholars have questioned the model's static nature regarding the three separate dimensions of attitude, which have been shown to be highly intercorrelated in other investigations (Eagly & Chaiken, 2007; Ostrom, 1969). Attempts to modify attitudes might be directed at both the affective and cognitive dimensions of attitudes (Katz, 1960; M. J. Rosenberg, 1956). For instance, if a political candidate attempts to communicate affect by undermining negative cognitions and thus affect about opponents to evoke more likability and elicit favorable beliefs in voters, efforts to modify attitudes might be directed at both the affective and cognitive dimensions of attitudes (Katz, 1960). The efficacy of this affective and cognitive persuasion matching effect has been demonstrated in experimental settings (Fabrigar & Petty, 1999). Furthermore, the prevailing perspective asserts that attitude measurement scales predominantly encompass generic aspects of affective and cognitive dimensions, employing semantic differential items across both dimensions (Crites et al., 1994). Alternatively, attempts have been made to model attitude as a one-dimensional construct (Millar & Tesser, 1986), or open-ended measurements have been employed to capture all three attitude dimensions (Haddock & Zanna, 2011).

Attitude conceptualization has been further informed by the notion of its stability, which can be categorized as either enduring or transient. This understanding acknowledges the capacity for attitudes to fluctuate along a continuum of awareness, ranging from the unconscious to the fully conscious (Bohner & Dickel, 2011; Eagly & Chaiken, 2007). Accordingly, the attitude continuum encompasses stable, memory-based evaluations and temporary, construction-based evaluations, which are formed from immediate, situational

information (Bohner & Dickel, 2011). *Stable attitudes*, which are often shaped by direct experiences or repeated exposure to consistent social or cognitive inputs, are expected to be enduring and resistant to change (Bohner & Dickel, 2011). These attitudes reflect long-term beliefs or feelings about an object or idea, as described by Fazio (1995). Conversely, attitudes are considered temporary constructions that are flexible and context-dependent, shaped by the most salient information available at the time of evaluation (Bohner & Dickel, 2011). Over time, *temporary attitudes* may stabilize through reinforcement and repeated exposure, transitioning into more enduring evaluations (Bohner & Dickel, 2011).

Defining attitude formation

Distinctions between the dynamic processes of *attitude formation* and *attitude change*, as well as related constructs such as *attitude reinforcement*, are salient issues in the psychological literature (see for reviews for example Bohner & Dickel, 2011; Eagly & Chaiken, 1993). As Miller (1980) proposed, the influence of persuasive communication can shape attitudes on several dimensions in the attitude process such as the *formation* of new attitudes as well as the *altering* of existing attitudes, and the *change* of attitudes. The initial formation of an individual's response to an object, or *attitude formation*, is evident in context when no attitude has yet been formed. For instance, when participants are exposed to sources with varying degrees of expertise and express varying degrees of certainty regarding an unknown issue (Holbert & Tchernev, 2012; Karmarkar & Tormala, 2010).

In comparison, *attitude change* is defined as the process through which individuals process information in a way that results in a modification of their existing evaluations (Petty & Briñol, 2010). Media has been shown to elicit attitude change when presenting compelling arguments or framing issues in ways that challenge the audience's current beliefs (Holbert & Tchernev, 2012). According to McGuire's (1985b, 1989) model, the effectiveness of attitude change is influenced by five factors, including the credibility of the source, the persuasiveness of the message, the medium and the channel through which the message is delivered, and the characteristics of the recipient. For instance, a message disseminated by a source with substantial credibility is more likely to elicit attitude change, particularly if it is articulated in a lucid, logical, and emotionally engaging manner (McGuire, 1989). Following the Second World War, there was a notable increase in the study of persuasion, driven by the prevailing geopolitical climate of the Cold War and advancements in telecommunications and television (Eagly & Chaiken, 1993). This

period saw researchers at the Yale School (Hovland et al., 1953) undertaking the exploration of the dynamics underlying *attitude change*. In this tradition, they investigated the role of variables such as message source, recipient, and content in shaping attitudes (Hovland et al., 1953; Hovland & Weiss, 1951).

As proposed in the "Past Attitudes are Still There" (PAST) model by Petty (2006), an employed metacognitive model, defined attitude change as a process in which pre-existing attitudes are retained in memory and tagged as invalid when a new attitude forms. To illustrate this process, an individual who holds a positive attitude toward smoking may adopt a negative attitude upon learning about its associated health risks, but the original positive attitude persists, albeit marked as false (Petty, 2006). The PAST model further predicts the existence of implicit ambivalence, characterized by individuals' unconscious experience of uncertainty due to the presence of both old and new attitudes (Petty, 2006). In contrast to attitude change, *attitude reinforcement* specifically refers to the enhancement of pre-existing attitudes or the strengthening of a preexisting reaction toward an object (Holbert & Tchernev, 2012). This phenomenon occurs when individuals encounter information that aligns with or reinforces their existing beliefs, thereby intensifying their existing attitudes (Fazio, 1990, 1995). One example of attitude reinforcement is evident in selective exposure processes, where individuals exposed to news articles that confirm their existing views on a political issue find that their existing opinions are strengthened rather than altered or newly formed (Knobloch-Westerwick, 2012). This reinforcing effect can be observed when people selectively seek out information that supports their beliefs, a phenomenon known as confirmation bias (Knobloch-Westerwick, Mothes, et al., 2015; Nickerson, 1998).

3.1.2 Attitude as Determinant of Behavior

Given the notion that behavior is predicted from attitude, an assumption has been made that a given behavior is consistent or inconsistent with a person's attitude. However, this relationship is largely based on intuitive considerations (Ajzen & Fishbein, 1977). In this context, consistency was defined as "to be logical or consistent for a person who holds a favorable attitude toward some object to perform favorable behaviors, or not to perform unfavorable behaviors, with respect to the object" (Ajzen & Fishbein, 1977, p. 889). Building upon the findings of Ajzen and Fishbein (1977), which posited that the empirically measuring of attitude consistency is a challenging endeavor, they advanced the argument that the conditions under which attitudes exert influence on behaviors should be clearly

delineated. Behavior has been described as comprising the action itself, the goal to which the action is directed, the context in which the action is performed, and the time at which the action is performed (Ajzen & Fishbein, 1977; Fishbein & Ajzen, 2009). Attitudes were regarded as the overall evaluative response to an object; nevertheless, they were described as being consistent with cognitions, or beliefs about the attitude object (Ajzen, 1989). It was posited that only attitudes that were considered a function of beliefs were considered salient for the individual and to have a causal impact (Ajzen, 1989).

Overall, the intention to perform a behavior or the behavioral intention has been considered the main antecedent of behavior (Fishbein & Ajzen, 1975). In this regard, behavior change theories have sought to ascertain which beliefs should be targeted in order to influence behavioral intentions and behavior change (Fishbein, 2000). According to Ajzen's Theory of Reasoned Action (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991), attitudes and behavioral intentions, which reflect one's plans to act in a certain way based on their attitudes, are key predictors of actual behavior. For instance, a positive attitude towards exercise often results in the intention to engage in regular physical activity, which subsequently manifests as consistent exercise routines (Norman et al., 2000).

Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB)

The *Theory of Reasoned Action* (TRA) explained intention-based behavior by identifying behavioral intention (BI) or the intention to engage in a specific behavior as the strongest predictor of behavior (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975). In turn, behavioral intention is influenced by the two primary factors of attitude toward the behavior (A) and subjective norms (SN) (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975). According to the aforementioned theoretical framework, considerations regarding the probable consequences of an act are given primacy. Individuals establish *attitudes* based on their expectations regarding the consequences of the act. In the event that they anticipate that performing the act will yield more positive than negative outcomes, a favorable attitude will be developed (Fishbein & Ajzen, 2009). Furthermore, attitudes are derived from the evaluation of one's beliefs about the behavior and the strength of those beliefs (Fishbein & Ajzen, 1975). Beliefs have been demonstrated to be influenced by several factors, such as personal experience, information behavior, and individual differences (Fishbein & Ajzen, 2009).

In accordance with Social Norms Theory (SNT) (A. D. Berkowitz, 2004; Perkins, 2002), the TRA anticipates that *perceived subjective norms* are derived from social influences and encompass beliefs and motivations to comply with the opinions of other individuals (see for example Ajzen, 1985). Social norms encompass the approval or disapproval of behaviors exhibited by what have to be done of significant individuals or groups which was summarized as *injunctive norms*¹⁸, as well as the extent to which these behaviors are exhibited by others in the group, termed *descriptive norms* (Cialdini et al., 1991). As Lapinski and Rimal (2005) have observed, the fundamental distinction between these two norm variants lies in the absence of social sanctions for noncompliance with the norm in the case of descriptive norms. However, the congruence or antagonism of these norms can vary depending on the specific circumstances (Lapinski & Rimal, 2005; Perkins & Berkowitz, 1986). Nonetheless, a discrepancy or literal inconsistency may emerge from the development of behavioral intentions to actual behavior, particularly in instances where the intended behavior is not realized (Ajzen & Fishbein, 2005; Sheeran, 2002).

In formulating the *Theory of Planned Behavior (TPB)*, Ajzen (1991) built upon earlier contributions from the Theory of Reasoned Action by incorporating *perceived behavioral control*, a concept developed by Bandura (1977a) and termed *self-efficacy*, or the ability to perform a given behavior as an additional factor influencing behavioral intentions (Ajzen, 1985, 1989). Behavioral control can be conceptualized as “a function of underlying beliefs, specifically, control beliefs weighted by the power of control factors” (Fishbein & Ajzen, 2009, p. 18). In the proposed theoretical model, behavioral control functions as exogenous variable, exerting a direct influence on behavior, as well as an indirect impact on behavior via behavioral intentions (Madden et al., 1992). This integrated approach offers a more precise modeling of the impact of persuasive communication efforts, as empirically documented by the observation that the inclusion of perceived behavioral control enhances the prediction of behavioral intention and behavior (Ajzen & Madden, 1986; Madden et al., 1992). Figure 7 illustrates the causal relationship among the variables by displaying an extended model integrating TRA and TPB by Ajzen and

¹⁸ In the realm of the TRA, injunctive norms were used as an angle of reference to describe people’s motivation to comply with the beliefs of important outcomes (Ajzen, 1985), which did not address descriptive norms, but it might be also a possibility that injunctive norms moderate the relationship between descriptive norms and behavioral intention accordingly and the influence of descriptive norms on behaviors to be higher when injunctive norms are strong and attenuated when injunctive norms are weak (Lapinski & Rimal, 2005; Rimal & Real, 2003).

Fishbein (2005). In addition to the original theoretical model of TPB, this model incorporates the influence of background factors, including personality traits, sociodemographic variables, and the information environment, which indirectly influence behavioral beliefs, normative beliefs, and control beliefs (Ajzen & Fishbein, 2005). Consequently, it was hypothesized that behavioral belief would influence attitude, normative belief would influence subjective norm, and control belief would elicit an effect on perceived behavioral control (Ajzen & Fishbein, 2005). Behavioral intention, was expected to be determined by attitude toward the behavior, subjective norm, and perceived behavioral control (Ajzen & Fishbein, 2005). The model posits that actual behavioral control moderates the effect of intentions on behavior (see Figure 7).

When individuals believe they possess the necessary skills and resources and perceive fewer external barriers, they are more likely to engage in the behavior (Ajzen, 2002). Conversely, low perceived behavioral control¹⁹ as moderator can reduce motivation and prevent action, even if attitudes and social norms are favorable (Ajzen, 2002). The interplay among attitude, subjective norm, and perceived behavioral control collectively shapes behavioral intentions²⁰, which in turn serve as a predictor of actual behavior (Ajzen, 2002). As Fishbein and Ajzen (2009) posited the overall premise of the model, the stronger the intention to perform a certain behavior, the more favorable the attitude and perceived norm, and the greater the perceived behavioral control.

From a critical standpoint, concerns regarding the absence of general and empirical concordance among the explanatory variables have been expressed, as evidenced by a lack of consensus in the intention-behavior relationship²¹ (Wicker, 1969). Nevertheless, there is substantiating evidence that the correlation between these constructs is consistent, as demonstrated for example by example Sheeran (2002) in a meta-analysis, which identified an overall correlation of .53 between behavioral intention and behavior. Furthermore, researchers have reached the conclusion that attitude can be a predictor of behavior under specific conditions, such as the presence of situational factors such as temporal

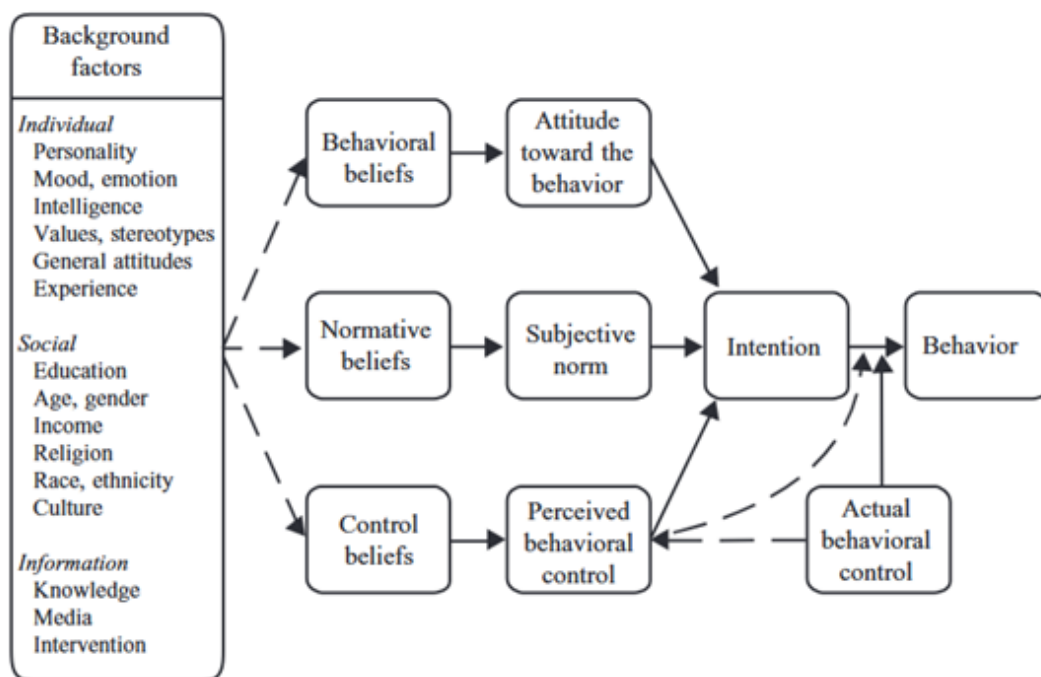
¹⁹ Due to empirical research supporting main effects, later TPB formulations (Ajzen, 2012; Ajzen & Fishbein, 2005) treated perceived behavioral control as a direct determinant of behavioral intention, alongside attitude and subjective norm. However, as Ajzen (2020) has noted, recent studies provide evidence for interaction effects in certain contexts.

²⁰ However, there is also a possibility for a correlation between attitudes, subjective norms, and perceptions of control. This is due to the fact that the anticipated outcomes can be expected to be based on the same information (Ajzen & Fishbein, 2005).

²¹ Fazio (1990) attributed ambiguity in attitude-behavior research to shifts from establishing the link between attitudes and behaviors (e.g., Fishbein, 1967), to identifying moderators (e.g., Zanna & Fazio, 1982), and then examining guiding processes (e.g., Ajzen & Fishbein, 1980).

stability (Sheeran et al., 1999) and individual moderator variables, for example motivation and cognitive capacity (Fazio, 1990). Notably, the TPB has had a considerable impact on the field of social psychological research, as evidenced by the publication of over 2,000 studies addressing this subject (Ajzen, 2020). Subsequent applications have emerged in domains such as health communication, environmental communication, and technology studies (Godin & Kok, 1996; Mathieson, 1991; Si et al., 2019).

Figure 7. Integrated model of Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB)



Source: Ajzen and Fishbein (2005, p. 194)

Technology Acceptance Model (TAM)

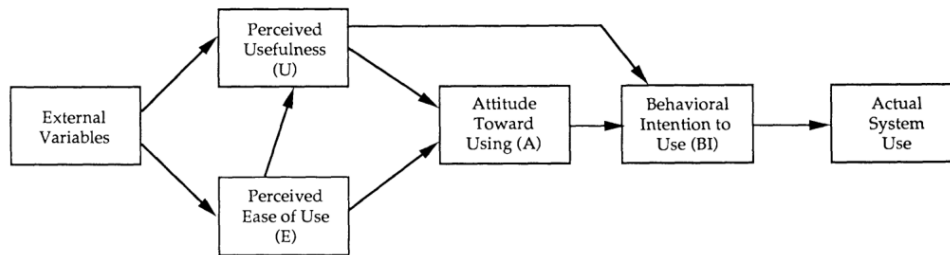
First developed by F. D. Davis (1989), the Technology Acceptance Model (TAM) has proven to be a useful framework for understanding the determinants of technology adaptation and by providing insight into behavioral changes in the context of technology. As F. D. Davis et al. (1989) outlined, the Technology Acceptance Model (TAM) is more applicable to specific contexts than the Theory of Reasoned Action (TRA), as it prioritizes technology adoption, for instance, regarding computer usage behavior rather than general human actions. The first factor of TAM is the *perceived usefulness* of an application or technology, such as enhancing job performance or providing a “positive user-

performance relationship” (F. D. Davis, 1989). When users perceive the technology as useful, *ease of use* becomes a pivotal factor in its acceptance. This ease of use is defined by the absence of difficulty or significant effort required to use the technology in comparison to other technologies (F. D. Davis, 1989). Importantly, the perceived ease of use of an innovation is a crucial factor in its adoption (see also chapter 2.3), as research indicates that the complexity of a technology is related to its perceived ease of use (E. M. Rogers & Shoemaker, 1971). In the context of the Technology Acceptance Model (TAM), *self-efficacy* (Bandura, 1982), defined as an individual's confidence in their ability to use a system effectively, aligns with perceived ease of use (F. D. Davis, 1989). A higher sense of self-efficacy corresponds to a greater perception of ease of use, thereby increasing the likelihood of system adoption (F. D. Davis, 1989). Outcome beliefs, defined as expectations regarding the beneficial outcomes that technology use will yield, also correspond to perceived usefulness (F. D. Davis, 1989). According to Bandura (1982), both factors influence behavior separately. Specifically, for technology adoption, users must both feel capable of using the system (self-efficacy) and believe it will provide value (outcome beliefs). However, as F. D. Davis (1989) have noted, self-efficacy can be considered as situation-specific, thus lacking a universal measure. Nevertheless, within the theoretical framework of the TAM, F. D. Davis (1989) underscored the significance of self-efficacy in influencing perceived ease of use and perceived usefulness of technology, thereby serving as a crucial predictor of user behavior.

Accordingly, the model paths of the TAM which are shown in Figure 8, postulate that technology usage is determined by behavioral intention (BI), ultimately influencing the usage of the technology (F. D. Davis et al., 1989). It was differentiated for behavioral intention (BI) as being jointly determined by the perceived usefulness (U), and the perceived ease of use (E) (F. D. Davis et al., 1989). Furthermore, based on U and EOU, a relationship between a person's attitude toward using the technology (A) and the behavioral intention to use (BI) as proposed in the Theory of Reasoned Action occurs (Ajzen & Fishbein, 1980; Fishbein & Ajzen, 1975). In contrast to the TRA, the TAM proposes also a direct effect from perceived usefulness (U) on behavioral intention (BI), considering that affect is not fully activated when deciding whether to use a particular technology, but rather based on cognitive decision rules of users how the system will approve their performance (F. D. Davis et al., 1989). The model also suggested a path from perceived usefulness (U) to be influenced by perceived ease of use (E), because other things being equal, the easier a technology is to use, the more useful it is expected to be (Venkatesh,

1999). Furthermore, it was anticipated that the impact of external variables, such as system accuracy, output quality, and educational programs, documentation, or system features such as menus, would be moderated by perceived usefulness (U) and perceived ease of use (E) (see Figure 8) (Benbasat et al., 1986; F. D. Davis, 1989).

Figure 8. The Technology Acceptance Model (TAM)



Source: F. D. Davis et al. (1989, p. 985)

A significant critique of TAM was its narrow focus on perceived usefulness as the primary determinant of attitudes toward technology adoption (Ajzen, 2020). Another limitation lies in its simplistic approach to perceived ease of use, as TAM assesses ease of use in terms of how easy it is to learn and control a given technology but does not consider other relevant control beliefs or factors such as the availability of technical support, the time allowed for adaptation, and how an individual's self-assessed technology skills can significantly impact perceived behavioral control (Ajzen, 2020). In its original formulation, TAM overlooked the pivotal influence of social norms, an essential element in other frameworks, such as TRA and TPB, in shaping behavioral intentions (see TRA and TPB in this chapter) (F. D. Davis et al., 1989). Addressing this critical gap, subsequent extensions of the TAM incorporated social influence variables (Venkatesh & Bala, 2008; Venkatesh & Davis, 2000). For instance, the later extension of TAM2 incorporated additional theoretical constructs on social influence processes, such as subjective norm, voluntariness, and image, and cognitive instrumental processes, for example job relevance, output quality, and result demonstrability (Venkatesh & Davis, 2000). An empirical examination of the proposed model demonstrated that TAM2 accounted for 60% of the variance in perceived usefulness and between 37% and 52% of the variance in usage intention (Venkatesh & Davis, 2000). The latest TAM framework (TAM3) identified individual differences (demographics or traits), system characteristics, social influence, and facilitating

conditions as additional determinants of perceived usefulness and perceived ease of use (Venkatesh & Bala, 2008).

The TAM has been widely applied to various technological contexts, including information systems, e-learning platforms, mobile applications, and healthcare technologies, to understand user acceptance and adoption behavior (Schepers & Wetzels, 2007). However, it can also be argued that its application to emerging technologies is limited to specific applications and contexts. One example of such a context can be found in the study of the adoption of generative AI in classroom settings by Ghimire and Edwards (2024). In order to extend the TAM to other technological fields, Huijts et al. (2012) developed the *technology acceptance framework* (TAF). The TAF integrates elements of the Theory of Planned Behavior (TPB) and the Norm Activation Model (NAM) (Schwartz, 1977), which models personal norms as a direct determinant of intention to act. In their study, intention to act was defined as a feeling of moral obligation to act in favor of or against a local hydrogen fuel station (see Huijts et al., 2012). A focal point of the TAF is the context of technology implementation, which serves as a crucial determinant of technology and behavior evaluation (Huijts et al., 2012). The implementation context encompasses psychological variables such as trust in the actors responsible for the technology, procedural fairness, and the fairness of the decision process that leads to the implementation. It also comprises distributive fairness, which is perceived fairness in the distribution of costs, risks, and benefits of the technology implementation (Huijts et al., 2012). This study has identified causal relationships concerning the intention to promote hydrogen fuel technology, including personal norms, positive affect, and the perceived effects of the technology. In contrast, relevant factors for the intention to act against the technology included personal norms, negative affect, and trust in the industry (Huijts et al., 2012).

3.2 Theoretical Background of Persuasion Theory

Attitudes, by their very nature, are prone to development through a variety of mechanisms, including social learning, direct experience, and persuasion. *Social learning*, in particular, stands as a salient conduit for the formation of attitudes (Bandura, 1977b). This process occurs through the adoption of attitudes by direct experience or by observing and replicating the behaviors of others, particularly influential figures such as family, peers, or media personalities (Bandura, 1977b). For instance, an individual might adopt their parents' political views or their peers' consumer preferences, illustrating the role of social

interactions in shaping attitudes (Bandura, 1977b). In contrast to social learning, *persuasion* denotes a deliberate attempt to exert influence over another individual, operating on the premise that the recipient is capable of undergoing a modification in their mental state (Perloff, 2023). Accordingly, persuasion can be regarded as a distinct form of social influence, encompassing the broad spectrum of how one individual's behavior influences another's thoughts or actions (Perloff, 2023).

Addressing the multifaceted outcomes of persuasion, G. R. Miller (1980) defined persuasive communication as any message designed to shape, reinforce, or change the responses of others. Among these outcomes, response change has garnered the most recognition in the context of value, belief, attitude, intention, or behavior modification (Cameron, 2009). It has been suggested that the influence of persuasion may be unintentional, in the event that social influence manifests when receivers respond to cues or messages not intended for their consumption (Perloff, 2023). However, if defined from the audience's perspective, any message that conveys an opinion or alters someone's attitude — even a casual social media post — be considered persuasion (Perloff, 2023). Consequently, in various overviews, persuasion has been described as limited with respect to intentional communication²² (G. R. Miller, 1980; Perloff, 2023). Thus, the deliberate effort of the communicator to change another's mind or attitude can be distinguished from the perspective of simply conveying messages (Perloff, 2023). Furthermore, persuasion frameworks, such as the Elaboration Likelihood Model (ELM), have been employed to examine media communication, under the premise that exposure to information by media is contingent upon subsequent attention, comprehension, and acquisition of the information presented, thereby facilitating attitude formation (Petty et al., 2009).

3.2.1 Information Processing of Persuasive Communication

Research into persuasion, particularly during the 1980s and 1990s, was guided primarily by cognitive process-oriented perspectives. Notable among these theories are dual-process theories, including the Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986a, 1986b) and the Heuristic-Systematic Model (HSM) (Chaiken, 1980, 1987), which are exemplars of theories that incorporate the two ends of the elaboration continuum.

²² In addition, coercive attempts are distinct from persuasion in that they do not involve free choice and include a credible threat of significant physical or emotional harm to those who refuse the directive. They also deprive the individual of some measure of freedom or autonomy and attempt to induce the individual to act contrary to their preferences (Perloff, 2023; Rosenbaum, 1986).

These models articulate the phenomenon through which individuals process information in either a quick and intuitive manner (i.e., heuristic/peripheral) or through a more deep and cognitive engagement (i.e., systematic/central) (Chaiken, 1980; Petty & Cacioppo, 1986b).

Elaboration Likelihood Model (ELM)

The *Elaboration Likelihood Model (ELM)*, developed by Petty and Cacioppo (Petty & Cacioppo, 1986a, 1986b), outlines two primary routes through which persuasion occurs. Attitudes, as the central outcome of the persuasion process, were defined as “general evaluations people hold in regard to themselves, other people, objects, and issues” (Petty & Cacioppo, 1986b, p. 127). Central factors that activate these two routes include motivation and ability to process the message (Petty & Cacioppo, 1986a, 1986b). Degrees of cognitive engagement with a message range from minimal to extensive processing and are represented on a continuous scale (Petty & Cacioppo, 1986a, 1986b). As Kitchen et al. (2014) summarized, the ELM has emerged as a prominent framework due to its clarity and structural organization, facilitating comprehension of the persuasion process. Additionally, the model's adaptability and extensive applicability enable it to produce varied outcomes across diverse contexts (Carpenter, 2015; Kitchen et al., 2014). The ELM's status as a foundational model in marketing and communication research has been solidified by its academic influence and widespread citation (Schumann et al., 2012). However, it has also been the subject of methodological criticism (Mongeau & Stiff, 1993; Stiff, 1986; Stiff & Boster, 1987), an issue that will be addressed in this chapter.

From a theoretical point of view, the ELM is characterized by seven postulates concerning the persuasion process, as depicted in Table 2. The ELM's first postulate, derived from Festinger's theory (1950, 1954) on social comparison processes, posits that individuals are motivated to hold correct attitudes (Petty & Cacioppo, 1986b). An attitude's correctness, as noted by Petty and Wegener (1999) can be regarded as its subjective evaluation, such as through evidence from reliable sources or the number of individuals who support an issue. Furthermore, individuals are seldom overtly motivated to be biased, yet they assume their biases are justified (Petty & Wegener, 1999). In the second postulate of the ELM regarding the elaboration continuum, it was stated that although individuals aspire to hold correct attitudes, the amount and nature of issue-relevant *elaboration* in which they are willing or able to engage to evaluate a message vary with individual and situational factors (Petty & Cacioppo, 1986b). An examination of the elaboration

continuum reveals a theoretical framework that quantifies the extent of cognitive processing, ranging “from no thought about the issue-relevant information presented to complete integration of these elaborations into the persons’ attitude schema” (Petty & Cacioppo, 1986b, p. 129). Consequently, the probability of elaboration is contingent upon the individual's motivation and capacity to assess the message (Petty & Cacioppo, 1986b).

Table 2. Overview of the seven postulates of the Elaboration Likelihood Model (ELM)

Postulate	Description
1. The Correctness Postulate	<i>People are motivated to hold correct attitudes.</i>
2. The Elaboration Continuum Postulate	<i>Although people want to hold correct attitudes, the amount and nature of issue-relevant elaboration in which they are willing or able to engage to evaluate a message vary with individual and situational factors.</i>
3. The Multiple-Roles Postulate	<i>Variables can affect the amount and direction of attitude change by: A) serving as persuasive arguments, B) serving as peripheral cues, and/or C) affecting the extent or direction of issue and argument elaboration.</i>
4. The Objective-Processing Postulate	<i>Variables affecting motivation and/or ability to process a message in a relatively objective manner can do so by either enhancing or reducing argument scrutiny.</i>
5. The Biased-Processing Postulate	<i>Variables affecting message processing in a relatively biased manner can produce either a positive (favorable) or negative (unfavorable) motivational and/or ability bias to the issue-relevant thoughts attempted.</i>
6. The Tradeoff Postulate	<i>As motivation and/or ability to process arguments is decreased, peripheral cues become relatively more important determinants of persuasion. Conversely, as argument scrutiny is increased, peripheral cues become relatively less important determinants of persuasion.</i>
7. The Attitude Strength Postulate	<i>Attitude changes that result mostly from processing issue-relevant arguments (central route) will show greater temporal persistence, greater prediction of behavior, and greater resistance to counter persuasion than attitude changes that result mostly from peripheral cues.</i>

Own illustration based on Petty and Wegener (1999)

Routes to attitude change

According to the ELM, attitude change occurs through the central or peripheral route of information processing (Petty & Cacioppo, 1986a, 1986b). As shown in Figure 9, the *central route* of persuasion involves high motivation and/or the ability to process a message, for example in the case of a message that is of high personal relevance to the receiver. Therefore, the motivation and ability of an individual to process the information is central to the elaboration of a message (Petty & Cacioppo, 1986b). When motivation and/or the ability to elaborate a message are high, central processing of the message occurs. In this mode, effortful processing of attitude-relevant information with critical evaluation of the arguments contained and issue relevant thoughts to the message takes place (Petty & Cacioppo, 1986b; Petty & Wegener, 1999). The elaboration process is defined as "the generation of thoughts in response to the information to which one is exposed," thereby extending beyond the mere comprehension of the arguments contained within the message (Booth-Butterfield & Welbourne, 2002, p. 156). Attitudes that are formed under the central route of information processing are expected to be enduring and resistant to counter persuasion (Petty & Cacioppo, 1986a, 1986b). Conversely, the *peripheral route* pertains to less effortful processing under conditions of low motivation and/or limited ability to process a message. In such cases, message receivers rely on cues or heuristics, which can result in a temporary shift in attitude (Petty & Cacioppo, 1986a, 1986b).

In accordance with the theoretical framework of the ELM, the *multiple roles of variables* have been demonstrated to influence the magnitude and direction of attitude modification. These variables can function as persuasive arguments, peripheral cues, and/or as factors that regulate the extent or direction of issue and argument elaboration (see Table 2) (Petty & Cacioppo, 1986b). The degree of effort in message processing is influenced by several factors, including the argument quality, personal relevance, personal responsibility, and the respondents' need for cognition (Petty & Cacioppo, 1986b). *Argument or message quality*, in this context, refers to the persuasiveness of the arguments (Petty & Cacioppo, 1986b). In a typical study design (see for example Petty et al., 1981), participants receive persuasive messages that varied in argument quality, or respective strong or weak arguments. After exposure, participants completed attitude assessments and manipulation checks, followed by a cognition recall task to evaluate their message processing to determine whether cognitive responses vary as a function of experimental conditions (Mongeau & Stiff, 1993). A strong message was defined as "one containing arguments (...) such that when subjects are instructed to think about the

message, the thoughts that they generate are predominantly favorable (Petty & Cacioppo, 1986b, p. 133). In contrast, a weak message was described as “one containing arguments (...) such that when subjects were instructed to think about them, the thought that they generate are predominantly unfavorable” (Petty & Cacioppo, 1986b, p. 133). It was further established that positive attitude change occurs when the thoughts are more favorable compared to those prior to message exposure (Petty & Cacioppo, 1986b). However, a negative attitude change effect, also known as the “boomerang effect,” was expected to occur when the thoughts were more unfavorable than those prior to message exposure (Petty & Cacioppo, 1986b).

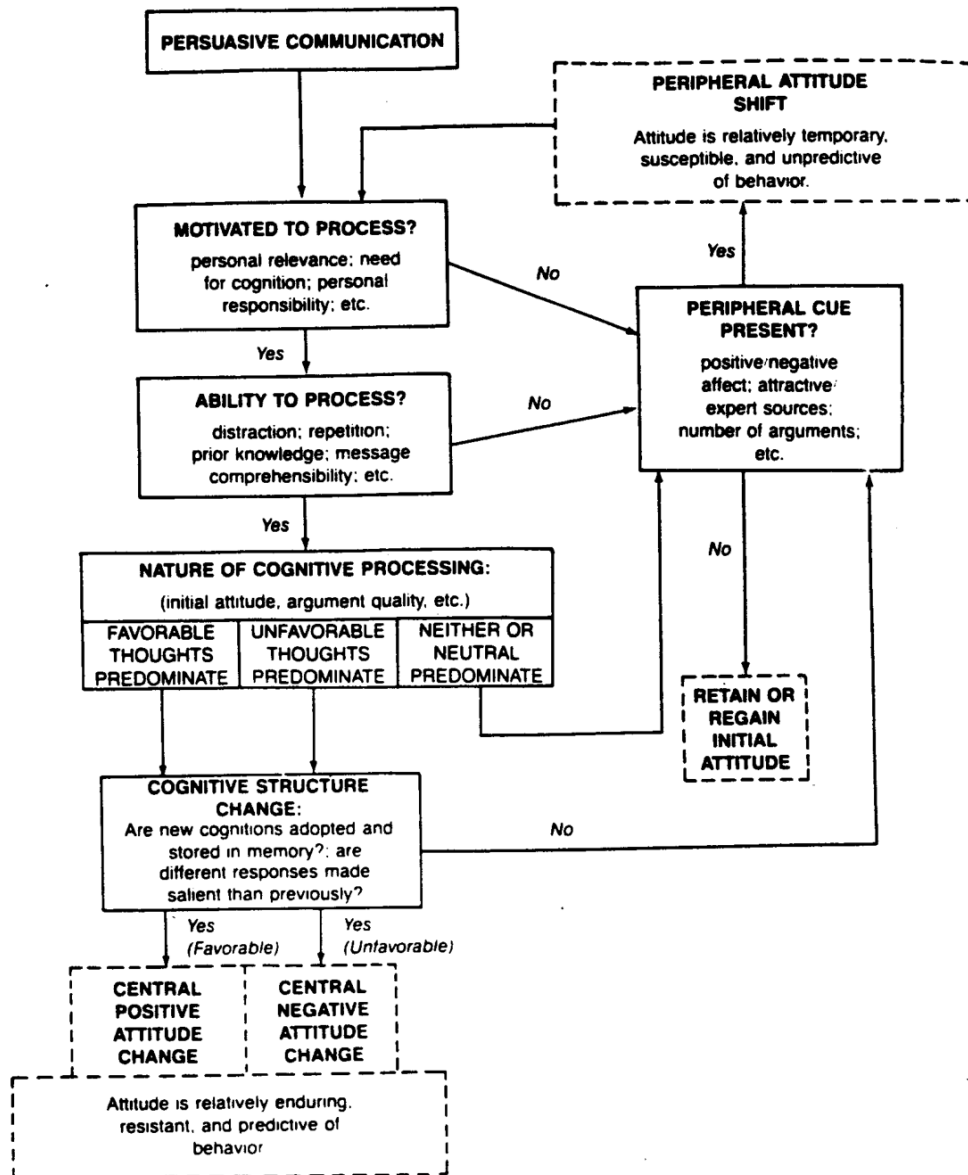
As displayed in Figure 9, under the condition of low motivation and/or ability to process the information, *peripheral cues* might affect attitudes in the absence of argument processing (see also the “Tradeoff Postulate”) (Petty & Cacioppo, 1986b). In such instances, the evaluation of arguments within a message is informed by simple decision cues (Petty & Cacioppo, 1986b). The potential of variables to function as peripheral cues was for example assessed by presenting a message comprising a varying number of arguments (e.g., 1 vs. 10) to evaluate the persuasiveness of this factor (Petty & Cacioppo, 1986b). Another example that falls under the category of peripheral processing can be seen in how credibility affects message reception (Petty & Cacioppo, 1986b). In this example, the persuasiveness of the communicator is more important than the message content (Petty & Wegener, 1999). For example, the attitude of the audience can be changed by a spokesperson with a high level of attractiveness who is promoting a product, even if the message content is not particularly compelling (Petty & Wegener, 1999). However, in the context of strong, weak, and mixed argument messages accompanied by a peripheral cue, Petty and Cacioppo (1986b) highlight that the cue exerted an equally influential effect on attitudes across all message types during pure cue processing.

Another mechanism through which variables can affect persuasion is through the extent and direction of message processing, which can occur according to postulates 4 and 5 in objective or biased processing (Petty & Cacioppo, 1981, 1986b). A given variable may increase or decrease persuasion through *objective means*, with its influence exerted on aspects such as message properties, situational variables that motivate behavior, source, or recipient (Petty & Wegener, 1999). For instance, the employment of positive framing, such as “If you stop smoking, you will live longer,” is anticipated to result in more extensive processing compared to negative framing, such as “If you don't stop smoking, you will die sooner.” However, positive framing is predicted to lead to less

processing than negative framing when individuals anticipate positively framed arguments (Smith & Petty, 1996). The impact of source expertise on message processing can be further demonstrated by comparing a high expert source to a low expert source (Petty & Wegener, 1999). A high expert source may lead to more differentiation between strong and weak arguments, while a low expert source may lead to less differentiation between strong and weak arguments (Petty & Wegener, 1999).

Furthermore, motivational and ability factors have been shown to lead to *biased processing* when people implicitly or explicitly prefer one judgment over another (Petty & Wegener, 1999). When a message is personally relevant to an individual, it has a tendency to generate positively biased processing, in which people evaluate the message favorably and accept it more readily. Conversely, if the message challenges or threatens one's values or identity, it leads to negatively biased processing, triggering resistance and counterarguments (Petty & Cacioppo, 1990; Petty et al., 1992). Moreover, when individuals perceive a message as compelling them to alter their opinions, they may experience psychological reactance and actively resist it (J. W. Brehm, 1966).

Figure 9. Elaboration Likelihood Model (ELM)



Source: Petty and Cacioppo (1986b, p. 126)

Heuristic-Systematic Model (HSM)

Also rooted in the tradition of message learning theory of persuasion, the *Heuristic-Systematic Model (HSM)*, developed by Chaiken (Chaiken, 1980, 1987), exhibits certain parallels as a dual-process model with the ELM (Petty & Briñol, 2012). Within the HSM, systematic processing has been defined as the careful analysis of all available information, a process requiring deep thinking, attention, and reasoning (Chaiken, 1980, 1987). Individuals engage in this mode when motivated and able to process information thoroughly, for example, when thinking carefully about the arguments presented. Conversely,

heuristic processing is characterized by its rapidity and reduced mental exertion, occurring even in circumstances where individuals may be lacking in motivation or time to engage in exhaustive thought relying on straightforward decision principles or cognitive shortcuts (Chaiken, 1980, 1987).

Heuristics, as an integral component of this cognitive process, have been conceptualized as “simple decision rules that were likely represented in memory” (Chaiken & Ledgerwood, 2012, pp. 251–252). Derived from social recognition research, heuristics are knowledge structures activating stored knowledge (Chaiken et al., 1989; S. Chen & Chaiken, 1999) that adhere to the principles of availability, accessibility, and applicability (Higgins et al., 1982). Therefore, heuristics influence attitudes when they are both accessible, as in the case of situational priming, and applicable, meaning they are perceived as a reliable basis for judgment (S. Chen & Chaiken, 1999). Rather than engaging in thorough argument analysis, individuals instead focus on readily apparent cues, such as a speaker's expertise, group affiliation, or the number of arguments presented. These heuristic shortcuts, exemplified by the prevalent notion that “experts know best,” facilitate rapid judgment formation without necessitating critical evaluation (Chaiken & Ledgerwood, 2012).

The two modes of information processing may occur independently; however, in contrast to the Elaboration Likelihood Model (ELM), the Heuristic-Systematic Model (HSM) suggests the co-occurrence of heuristic and systematic processing (S. Chen & Chaiken, 1999). As specified in the *additivity hypothesis*, when heuristic cues (e.g., a likable communicator) and systematic processing (arguments of high quality) are congruent, both can contribute independently to attitude change (Chaiken & Maheswaran, 1994; S. Chen & Chaiken, 1999). Furthermore, the *attenuation hypothesis* suggests that systematic processing can override the effects of heuristic processing when a source cue and message content are contradictory in their implications for message validity (Chaiken & Maheswaran, 1994; S. Chen & Chaiken, 1999). In the context of systematic processing, the availability of judgment-relevant information exceeds that of heuristic processing, and information may contradict heuristic-based judgments (Chaiken & Maheswaran, 1994). For instance, in situations where a credible source is accompanied by weak arguments or a noncredible source by strong arguments, systematic processing alone determines attitudes (Chaiken et al., 1989).

Within the *bias hypothesis* of the Heuristic-Systematic Model (HSM) it was posited that the two processing modes are interdependent (Chaiken & Maheswaran, 1994).

Heuristic cues create expectations about later information, which can then bias how systematically processed information is interpreted and evaluated (S. Chen & Chaiken, 1999). When individuals encounter a persuasive message that is ambiguous or contains both strong and weak arguments, their initial reliance on heuristic cues—such as source credibility, expertise, or consensus—shapes their interpretation of the message. For example, the validity of persuasive messages is often judged in terms of the number of valid arguments they contain when they originate from an expert source as opposed to a non-expert source (Chaiken et al., 1989; Chaiken & Maheswaran, 1994).

In accordance with the *least effort principle* (Allport, 1954), individuals demonstrate a preference for attitudinal decisions that require minimal cognitive effort, exhibiting a tendency to favor heuristic processing over systematic processing when given the opportunity (Chaiken et al., 1989). As demonstrated by Thompson et al. (1994) this tendency was evident in a priming experiment centered on accountability and judgment. In this study, participants were held accountable for their judgments, which led to an increased reliance on systematic information processing. However, this reliance was not absolute; it was accompanied by the consideration of both supportive and contradictory information regarding a target individual. A decline in priming effects was observed as a result (Thompson et al., 1994). In contrast, participants who were not held accountable exhibited a greater reliance on heuristics, demonstrating stronger priming effects (Thompson et al., 1994). Taken together, these findings indicate that heuristic processing holds the greatest influence in situations where individuals lack motivation for systematic processing. Nevertheless, under circumstances where motivation and capacity are present, the concurrent manifestation of both phenomena becomes a possibility, with systematic processing serving to attenuate heuristic effects (Bohner et al., 1995).

However, the *sufficiency principle* posits that individuals strive to maintain a balance between minimizing cognitive effort and maximizing confidence that a given judgment aligns with other relevant motives (Chaiken et al., 1989; S. Chen & Chaiken, 1999). However, the extent of information processing is influenced by both an individual's actual level of confidence in their judgment and their desired level of certainty in a given situation (Maheswaran & Chaiken, 1991). Within the context of judgmental confidence, the continuum extends from perceivers' actual confidence to their desired confidence, also referred to as their sufficiency threshold or the “point at which perceivers feel confident that the judgment will satisfy their currently operative motives” (S. Chen et al., 1999, p. 45). Systematic processing has been demonstrated to increase subjective confidence to

a greater extent than heuristic processing (S. Chen et al., 1999). When motivation is high, individuals seek increased confidence, thereby widening the gap between actual and desired certainty (S. Chen et al., 1999). This, in turn, triggers systematic processing. Conversely, low motivation has been shown to reduce this gap, rendering heuristic processing sufficient for judgment (S. Chen et al., 1999).

In overviews of the HSM, the aspect of *multiple motives* was highlighted, identifying three key motives driving information processing that influence whether individuals engage in heuristic processing or systematic processing, depending on their goals and the context of the persuasive message (Eagly & Chaiken, 1993). *Accuracy motivation*, in turn, refers to the motivational basis of attitude formation and the desire to form accurate judgments or attitudes and was described as open-minded process (Chaiken et al., 1989). Individuals motivated by accuracy tend to prioritize evaluating the strength and quality of arguments in a message, leading them to engage in systematic processing, where they thoroughly analyze information to make informed and accurate decisions (Chaiken et al., 1989). However, heuristic-oriented perceivers may utilize heuristics such as expertise to form attitudes (Chaiken et al., 1989). Nevertheless, accuracy-motivated systematic processing may be biased by cues or individual variables such as prior knowledge (Chaiken et al., 1989). Conversely, *defense motivation* entails the selective employment of heuristics to defend or validate pre-existing attitudes and beliefs, thereby manifesting as a close-minded process (Chaiken et al., 1989). For individuals driven by this motivation, the objective is to ascertain the validity of their prevailing attitudes and discredit opposing viewpoints (Chaiken et al., 1989). Individuals driven by defense motivation may engage in either systematic or heuristic processing (Chaiken et al., 1989).

Another salient motive is the *impression management motivation* (Tetlock, 1983), characterized by the use of simple rules to guide the attitude position with the inclination to express attitudes that are deemed socially acceptable or favorable to others. Individuals motivated by impression management seek to present themselves in a manner that will be positively evaluated by others (Chaiken et al., 1989). Consequently, the manifestation of systematic or heuristic processing, driven by the pursuit of impression management, is contingent on individual and situational factors. For instance, when individuals are unaware of others' positions, they are more inclined to adopt the attitudes of others, engage in issue-relevant thinking, and form a socially desirable attitude. Conversely, when individuals are aware of others' positions, they are more likely to employ an agreement heuristic, aligning their attitudes with those of others (Chaiken et al., 1989; Tetlock, 1983).

The MODE model

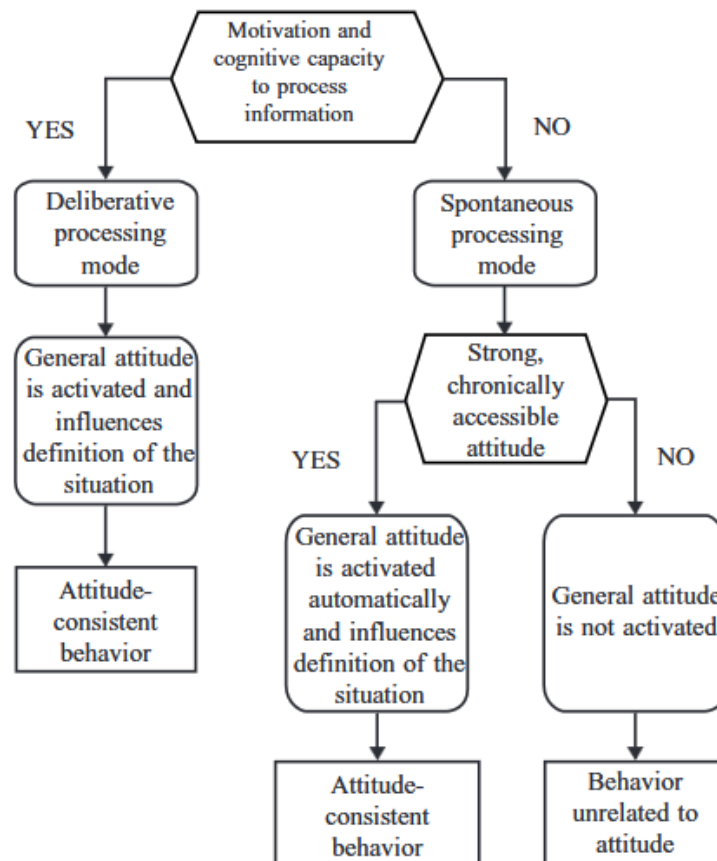
In integrating the perspective of information processing with the outcome of behavior change, Fazio (Fazio, 1990; 1986) developed the MODE model. Within this framework, it was theorized that general attitudes²³ could influence or bias perception and judgments of information relevant to the attitude object (Ajzen & Fishbein, 2005; Eagly & Chaiken, 1998). This notion was described by Ajzen and Fishbein (2005) as being consistent with the expectancy-value model of attitude (Kruglanski et al., 2018) to influence the person's attitude toward the behavior in accordance with the valence of the general attitude. Moreover, the process of attitude activation is central to the MODE model (Fazio, 1990; Fazio et al., 1986). The likelihood of automatic activation of an attitude upon is contingent on the strength of the object-evaluation association in memory, suggesting that individuals who repeatedly express attitudes toward particular objects exhibit more rapid ability to make fast positive or negative evaluations (Fazio, 1990). As a case in point, normative information may be retrieved from memory and exert an influence upon the evaluation of a given situation. The attitudinal congruence of the individual's evaluation determines the probability of demonstrating attitude-behavior consistency (Fazio, 1990). In line with the two other reviewed dual process models in this chapter, attitudes can be activated in either a controlled or deliberative manner and in an automatic or spontaneous fashion (Fazio, 1990; Fazio et al., 1986).

As Figure 10 shows, this process is driven by motivation and opportunity as determinants. In the presence of high motivation or cognitive capacity, individuals construct attitudes in an effortful manner on the deliberative processing mode, and attitudes are activated (Fazio, 1990). The following step in this process is the formation of attitude consistent behavior (Fazio, 1990). Whereas when motivation or cognitive capacity are low, individuals rely on the spontaneous processing mode, whether an attitude is accessible determines if the attitude is activated automatically with an evaluative association of the attitude object, resulting in attitude consistent behavior (Fazio, 1990). In the event of an insufficient attitudinal association to be activated, behavior occurs that is not attitude-based. Instead, it is activated by cues associated with the attitude object or behavior (Fazio, 1990). Researchers found a relation between the degree of accessibility, also referred to as attitude strength, and the latency of responses to questions (Fazio, 1990). Specifically, faster responses were observed to occur in response to more accessible

²³ General attitudes were described by Ajzen and Fishbein (2005) as attitudes toward physical objects, institutions, ethnic or religious groups.

attitudes (Fazio & Williams, 1986). Furthermore, the intervening variables of interest, involvement, and direct experience with the attitude object have been shown to foster the emergence of strong attitudes, as indicated by the reduced response latency (Fazio, 1995). Empirically, the model has been employed in the context of voting choice, where it has been observed that attitudes toward the candidates that are relatively accessible and of low latency exert a more significant influence on behavior for participants than attitudes that are relatively inaccessible (Fazio & Williams, 1986). However, within the MODE framework, the influence of attitudes on behavior is contingent upon their activation, with strength serving as a sufficient condition for such activation. (Fazio, 2001).

Figure 10. The MODE model



Source: Ajzen and Fishbein (2005, p. 184), illustration of the MODE model by Fazio (1990)

The Unimodel of Persuasion

Most notably, Kruglanski and Thompson (1999) criticized the two routes of information processing of the ELM and HSM, stating that the fundamental difference between these

two approaches lies in the nature of the information provided to support a conclusion, as opposed to a more intrinsic difference in the persuasion process itself. In response they introduced the *Unimodel of Persuasion (UM)*, which argued that persuasion does not necessarily involve two pathways, but that persuasion is based on a single, continuous process (Kruglanski & Thompson, 1999). The theoretical assumptions of the UM were based on the Lay Epistemic Theory (LET) of the processes governing the formation of subjective knowledge (Kruglanski, 1989a), which formulates attitude formation as dependent on the individual's cognitive capacity (Higgins et al., 1982; Kruglanski & Thompson, 1999).

According to LET, judgmental activity is initiated when there is a discrepancy between an individual's actual and desired epistemic states (Kruglanski & Thompson, 1999). In this regard, the discrepancy in question is determined by the individual's motivation to attain accuracy at the time in question. It has been demonstrated that a higher motivation to achieve accuracy results in a greater degree of information processing (Kruglanski & Thompson, 1999). Beyond its initiating and terminating functions, motivation exerts a substantial influence on the amount and direction of information processing during a persuasive encounter (Kruglanski & Thompson, 1999). Motivation is a critical factor in shaping individual engagement with information. When confronted with uncertainty, individuals with a higher need for non-specific closure tend to seek a swift resolution, often at the expense of rigorous analysis. In such cases, the level and type of motivation directly influence the extent to which individuals engage with information, potentially leading to reduced information processing (Kruglanski & Thompson, 1999). Conversely, a strong motivation for accuracy, or more specifically the avoidance of closure, leads to more extensive and systematic information processing (Kruglanski & Thompson, 1999).

In the Unimodel a strong emphasis is placed on cognitive ability, which has been further specified as capability and capacity (Kruglanski & Thompson, 1999). Thus, the concept distinguishes between capability as a "software aspect" of cognitive ability and accessibility, which is stored in an individual's memory and selected or made operational in particular circumstances (Kruglanski & Thompson, 1999). Cognitive capacity also referred to "hardware aspects" or the mental state of the individual, such as energy levels or cognitive load (Kruglanski & Thompson, 1999). Kruglanski and Thompson (1999) tested whether persuasion depends on processing effort rather than on the distinction between heuristic cues and arguments. In one experiment, participants read a detailed

description of a communicator (expert vs. non-expert) followed by an equally long argument for an additional university exam. Under high motivation (exam at their university), expertise led to an influence on attitudes, whereas under low motivation (exam elsewhere) there was no effect (Kruglanski & Thompson, 1999). Further research confirmed that when heuristic cues were as complex as arguments, they required effortful processing, just like arguments (Pierro et al., 2005). It was concluded that these processing effects were independent of peripheral source cues or arguments, supporting a single-process model of persuasion (Erb & Kruglanski, 2005; Pierro et al., 2005).

Theoretical and empirical critiques of persuasion models

Despite the challenges posed by the complexity of persuasion models in addressing the underlying psychological processes involved, there is a growing recognition of the need for a more comprehensive assessment of the causal mechanisms underlying persuasion (Eagly & Chaiken, 1993; Mongeau & Stiff, 1993). While persuasion studies have examined the links between message processing and cognitive responses, as well as message processing and attitude or behavior change, they have often neglected to consider the direct effect of cognitive responses on attitude or behavior change (Mongeau & Stiff, 1993). Consequently, it has been argued that in ELM studies, the validity of the full model is assumed without providing direct evidence to support this assumption (Mongeau & Stiff, 1993). For example Perloff (2023) posited that falsifying ELM predictions is challenging because of the ability of alternative explanations to account for observed effects. In the context of attitude modification, the assumption is made that it can be attributed to persuasion, despite the absence of clarity regarding the specific mechanism (Perloff, 2023). Conversely, the absence of observable attitude change does not necessarily refute the efficacy of the persuasive stimulus under scrutiny. Rather, it suggests that the specific persuasive cue in question was unsuccessful in its intended purpose (Perloff, 2023). In order to model the role of attitude activation in information processing, the MODE model (Fazio, 1990; Fazio et al., 1986) can be considered a useful theoretical stance.

This flexibility in causal attribution of variables renders it difficult to directly challenge the discussed models, as persuasion can be attributed to alternative, unspecified mechanisms (A. J. Cook et al., 2004). In this vein, another noteworthy point about the typical study design is highlighted by Carpenter (2015), who contends that the ELM is more suitable for explaining attitude formation than attitude change (see also M. A. Hamilton et al., 1993). This is due to the fact that the model's predictions seem to be applicable

in circumstances where individuals form new attitudes regarding unfamiliar subjects, as for example evidenced by Petty et al. (1981) in the context of students' initial encounter with the concept of a comprehensive graduation examination. Empirical substantiation of attitude change has been discussed as requiring researchers to employ a pre- and post-exposure measurement approach, while the majority of studies employ posttest-only designs and operate under the assumption that random assignment accounts for pre-existing attitudes (Carpenter, 2015).

The theoretical assumptions of the Elaboration Likelihood Model (ELM) have been the subject of considerable criticism, particularly with regard to its concept of "multiple functions" (Stiff, 1986; Stiff & Boster, 1987). Critics claimed that the ELM's broad scope can explain all possible outcomes, but it doesn't provide clear, specific predictions for persuaders (Kitchen et al., 2014). As Petty and Wegener (1999) clarified, the initial misinterpretation of the ELM stemmed from the assumption that variables serve a singular, discrete role in the process of attitude change. However, in light of the multifaceted roles of variables in the persuasion process posited by Petty and Colleagues (Petty & Cacioppo, 1986b; Petty & Wegener, 1999), the ELM could be regarded as a descriptive framework, as it lacks a priori explanations for why certain variables, such as arguments or prior knowledge, influence persuasion in particular ways (Eagly & Chaiken, 1993). Accordingly, the persuasive argument that is elaborated on under central route conditions may also be subject to alteration when influenced by other circumstances (O'Keefe, 2002). In light of the aforementioned multiple functions of the variables, some critics have argued that the model specifications are too vague, making the model difficult to test and falsify (Mongeau & Stiff, 1993; O'Keefe, 2002).

It is notable that the limited assumption of two-process information dissemination was mitigated in the Heuristic-Systematic Model (HSM) (Chaiken, 1980, 1987) by specifying conditions under which heuristic and systematic processing co-occur, for example when message content and source cues for both processing modes are congruent (Chaiken & Maheswaran, 1994; S. Chen & Chaiken, 1999). According to Erb and Kruglanski (2005), the Unimodel of Persuasion (UM) has been shown to have certain advantages over traditional dual-process theories. One key strength of the UM is its methodological clarity, as it reveals that observed differences in persuasion effects may result from complexity and length rather than a fundamental distinction between heuristic cues and arguments (Stroebe, 1999). The UM's flexibility has also been acknowledged, as it allows for

individual differences in the processing of persuasive messages, depending on motivation and cognitive capacity (Strack, 1999).

However, a critique of the Unimodel of Persuasion (UM) has been advanced by Petty et al. (1999), who have cited concerns that the model may overlook crucial qualitative distinctions in cognitive processing. They made reference to research (Petty & Cacioppo, 1984) which demonstrated a divergence in recipient behavior depending on the effort expended. Specifically, under low effort conditions, recipients prioritized the quantity of arguments, while under high effort, they placed greater emphasis on the quality of the arguments (Petty & Cacioppo, 1984). This observation led Petty et al. (1999) to pose the question of whether the act of counting arguments constitutes a fundamentally distinct process from evaluating content. In response, Erb and Kruglanski (2005) contended that, while these processes involve distinct cognitive operations, persuasion theory is concerned with how evidence informs judgments, not how it is encoded or processed. It was ultimately argued that, while there may be differences in the psychological processes underlying counting and content evaluation, both serve the same functional role in persuasion by providing evidence on the influences on attitudes (Erb & Kruglanski, 2005). It is therefore evident that a primary benefit of the Unimodel lies in its integration of other theories, such as cognitive consistency models (Festinger, 1957), and the theory of planned behavior (Ajzen, 1991).

Accordingly, the evaluation of argument quality within the ELM has given rise to numerous concerns, particularly with regard to its conceptual framework and empirical implementation (Areni & Lutz, 1988; O'Keefe, 2002). Johnson and Eagly's (1989) meta-analysis identified a researcher bias, which they termed as "Ohio State effect".²⁴ According to this study, researchers affiliated with The Ohio State University (OSU) consistently found the predicted interaction between involvement and argument quality, while researchers not affiliated with OSU did not (Johnson & Eagly, 1989). Additionally, the ELM lacks clarity on what constitutes a strong or weak argument (O'Keefe, 2002). Petty and Cacioppo (1986b) delineate strong arguments as those that elicit predominantly positive thoughts, and weak arguments as those that generate mostly negative thoughts. Empirical studies assessing argument quality typically employ thought-listing measures, wherein participants are prompted to record their reactions subsequent to exposure to a message (Brock, 1967; Greenwald, 1968). However, this approach obscures the

²⁴ However, as Carpenter (2015) summed up, this OSU effect seemed to have declined, as most studies since the publication of the ELM found an interaction between argument quality and involvement.

distinction between argument quality and message valence, rendering it ambiguous whether persuasion is driven by the argument itself or by pre-existing attitudes toward the message (Areni & Lutz, 1988). For instance, Stiff (1986) contended that defining argument quality based exclusively on message recipients' cognitions undermines its explanatory potency. ELM's critique underscores its subjectivity and measurement challenges. To effectively test the ELM, it has been discussed that strong and weak arguments should be distinguished based on their persuasive impact rather than their inherent qualities (O'Keefe, 2002).

Despite these shortcomings, dual-process models have made significant contributions to understanding the psychological mechanisms behind persuasion and provide a framework for exploring how various situational and individual variables affect attitudes (A. J. Cook et al., 2004). These models remain valuable for their comprehensive, process-oriented approach, although some argue that they function more as a descriptive framework than a testable theory (Stiff, 1986). In addition, the ELM has been used particularly in the context of education and training, with a particular focus on narrative persuasion (Slater & Rouner, 2002), which may also be useful for research on how digital platforms and their inherent cues influence attitudes (Perloff, 2023).

3.2.2 Overview on Influential Factors

Information processing theories, which were elaborated in Chapter 3.2.1, as well as a broader range of persuasion frameworks, such as the Yale Model of Communication of Persuasion (Hovland et al., 1953) and McGuire's communication model (1985b), have been developed to model influential factors on attitude formation. In addition to the formation of attitudes, it can be posited that attitudes towards objects can influence the performance of a specific behavior by biasing perception of the behavior's likely consequences (Fazio, 1990). As displayed in Figure 11, the communication and persuasion process can be organized according to relevant independent variables in this context such as the message, the source, the audience, and the communication context²⁵, which have an influence on the outcomes of attitude, behavioral intention, and behavior (McGuire, 1985b).

²⁵ The context of communication has been attributed to persuasion strategies such as distraction, forewarning, and repetition of the message (see for example Petty & Wegener, 1998a). However, these factors fall outside the scope of this review.

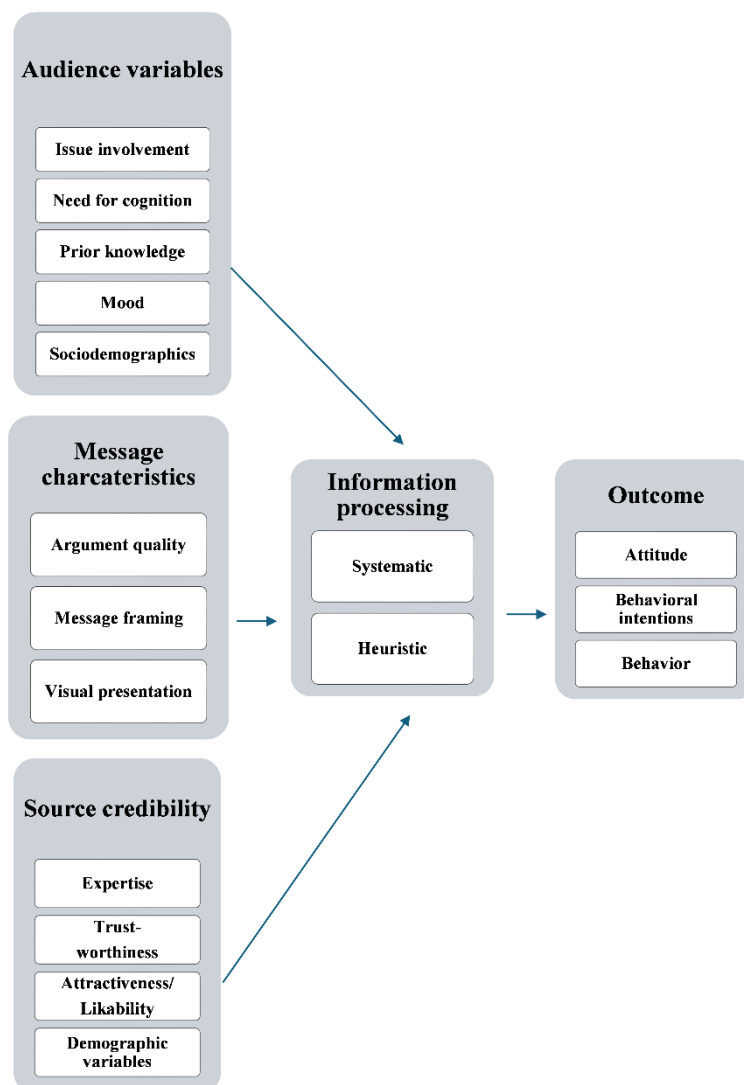
However, beyond the direct effects of message and source variables, interaction effects have been demonstrated to play an essential role in the formation of attitudes (Hovland et al., 1949; Petty et al., 2009). Consequently, the characteristics of the recipient, including their prior attitudes, motivation, and cognitive capacity, have been shown to significantly affect how individuals process and respond to persuasive messages (Petty & Cacioppo, 1986a, 1986b). In the context of dual-process models, variables that affect the motivation and ability of message processing have been introduced conceptually and tested experimentally (Petty & Cacioppo, 1986a; Petty & Wegener, 1999). Within the ELM, the most salient predictor of message elaboration likelihood is issue involvement, which delineates the personal relevance of the message to the receiver (Petty et al., 1981). Moreover, respondents need for cognition (NFC) (Cacioppo & Petty, 1982), prior knowledge of an issue (Wood et al., 1985), and their mood (Petty et al., 1993), have been identified as critical factors in message processing.

Message effectiveness is contingent upon the content and structure of the message. With respect to message structure, the Yale Model (Hovland et al., 1953) emphasized aspects such as the clarity of the message, the strength of the arguments, and the use of emotional appeals. In general, messages that are clear, well-structured, and emotionally engaging are more likely to be persuasive (Hovland et al., 1953). Furthermore, the model takes into account the impact of different message types, such as one-sided versus two-sided arguments, on the probability of persuasion (Hovland et al., 1953). The quality of the argument has been identified as a salient feature of persuasive messages, exerting influence on the extent of message processing under specific conditions of motivation or ability (Petty & Cacioppo, 1984, 1986a). Additionally, message framing has been delineated as a pivotal factor in message processing and attitude formation (Maheswaran & Meyers-Levy, 1990; Smith & Petty, 1996).

In the context of newspaper communication and effects, the application of media framing theory is imperative in this regard, as it elucidates the structuring of information, thereby influencing audience perceptions and attitudes toward a given issue (Entman, 1993; Lecheler & De Vreese, 2011). As indicated in the extant literature, prevalent strategies employed to accentuate particular aspects of emerging technologies include emphasis framing (Luong et al., 2019) and equivalence framing (see for example Levin et al., 1998). It has also been observed that the message context encompasses the visual presentation of newspaper content, which has been empirically demonstrated to influence processing mechanisms, particularly in the peripheral route of attitude formation (Trumbo,

1999; Zillmann et al., 1999). Furthermore, the credibility of a source has been demonstrated to play a significant role in attitude formation, as evidenced by investigations into the dimensions of expertise, trustworthiness, and likeability (Chaiken, 1980; Hovland et al., 1953; Hovland & Weiss, 1951). Researchers have characterized source expertise as a peripheral cue or heuristic, indicating that it exerts a more substantial influence in conditions characterized by low motivation or limited ability to process a message (Chaiken, 1980; Petty et al., 1981).

Figure 11. Variables in the persuasion process



As for example Mongeau and Stiff (1993) have noted, experimental investigation is necessary to determine the causal order of intervening variables in the persuasion process. Such experiments include varying variables, such as argument quality, source characteristics, and issue involvement, in order to detect whether and how these attributes affect audiences' cognitions and attitudes. The subsequent sections will outline the theoretical perspective of determinants of attitude formation concerning the factors of the audience, the message, and the source of communication. This will be achieved by discussing relevant studies on these effects, which are summarized in Table 3. Moreover, critical points of the procedure of persuasion studies will be reviewed concerning causal relationships between variables and study design.

Audience variables

Persuasion frameworks acknowledge that individuals vary in their cognitive capacities, including their susceptibility to persuasion or their level of engagement with the message topic. These factors can influence the effectiveness of messages (Petty & Cacioppo, 1986a; Petty & Wegener, 1999). According to this premise, individuals with high motivation and/or ability are more likely to engage in central or systematic processing, while those with lower motivation and/or ability may rely more on peripheral cues or heuristics (Chaiken, 1987; Petty & Cacioppo, 1986a).

Issue Involvement

In the ELM, issue involvement²⁶ was identified as a primary predictor of the manner in which attitude change is induced, either via the central or peripheral route (Petty & Cacioppo, 1986a, 1986b; Petty et al., 1981). The concept of issue involvement has also been summarized under the umbrella of outcome-relevant involvement, with the aim of elucidating the cognitive processes that occur at various levels of involvement (Johnson & Eagly, 1989). However, it is crucial to note that involvement can be situated along a *personal relevance*²⁷ continuum (Petty & Cacioppo, 1990), whereby an issue possesses significant consequences for an individual's personal life (Apsler & Sears, 1968).

Research in this realm has demonstrated that high-involvement messages elicit greater personal relevance than low-involvement messages, thereby enhancing the

²⁶ Furthermore, an alternative distinction of involvement is response involvement, which refers to the attitude response that is in concordance with situational rewards (Petty et al., 1983).

²⁷ For the empirical studies of this dissertation this view of personal relevance perception of individuals towards emerging technologies will be adopted as a definitional starting point.

cognitive effort required to evaluate message arguments (Petty & Cacioppo, 1979b; Petty et al., 1981). Furthermore, peripheral cues, such as source expertise, have been shown to influence perception to a greater extent under conditions of low than high involvement (Chaiken, 1980; Petty et al., 1981). In experimental studies, issue involvement is manipulated by assigning participants to groups, for example, by providing participants with information regarding the issue and its personal relevance. Classic ELM studies, for instance, have been conducted in the form of issues for students referring to their own universities (high involvement condition) or to a distant university (low involvement condition) (Petty & Cacioppo, 1979b). A foundational study on the influence of issue involvement was conducted by Petty et al. (1983) (see also Table 3), where they manipulated involvement (low or high), as well as argument quality (strong or weak arguments), and a source cue (celebrity or non-celebrity status) to an advertisement. Depending on the level of personal relevance, there was, in line with the theoretical assumptions of the ELM, a greater effect of argument quality under high involvement conditions. Conversely, the effect of the source cue was found to be more pronounced under low than high involvement conditions (Petty et al., 1983).

Need for cognition

The variability in individuals' message processing can be attributed to cognitive differences in message processing or their need for cognition (NFC) (Cacioppo & Petty, 1982; Petty & Cacioppo, 1986a). An individual's need for cognition can be defined as “the tendency for an individual to engage in or enjoy thinking” (Cacioppo & Petty, 1982, p. 116). According to ELM assumptions, individuals with a high need for cognition are likely to elaborate message arguments on the central route, while individuals with a low need for cognition are less likely to do so (Petty & Cacioppo, 1986b). Furthermore, the direction of elaboration has been found to exhibit an interaction effect, with the effect being more evident for individuals with high NFC and less evident for individuals with low NFC (Petty & Cacioppo, 1986b). This has been proven in experimental investigations concerning message effects, while people high in NFC tend to have stronger attitudes than those low in NFC (Priester & Petty, 1995) and also might showing more attitude polarization (Smith et al., 1994). Nonetheless, studies have revealed that NFC has the potential to interact with other variables, including the argument quality and the participant's mood (see Table 3. Overview on effects of variables in persuasion studies, for example Petty et al., 1993; Smith & Petty, 1996). In this sense, also low NFC individuals can be motivated

to scrutinize the message arguments if situational circumstances are motivating. For example, if the message is of high personal relevance (Axsom et al., 1987), or if the source of the message is potentially untrustworthy (Priester & Petty, 1995).

Prior knowledge

In determining the information processing, the *prior knowledge* of an issue is essential, or as described in the ELM the context of biased processing when prior knowledge or schema-driven knowledge is high and therefore adjusted with existing knowledge and beliefs (Petty & Cacioppo, 1986b). Therefore, higher issue-relevant knowledge is associated with greater scrutiny of messages relevant to individuals knowledge than lower issue-relevant knowledge (Petty & Wegener, 1998a; Wood et al., 1995). In their (1985) study, Wood et al. investigated the influence of message quality, message length, and prior knowledge on attitudes regarding environmental preservation. Their findings indicated that individuals with extensive prior knowledge demonstrated greater resistance to counter attitudinal appeals. These participants exhibited the capacity for critical evaluation of message arguments, with more robust arguments eliciting more substantial attitude changes, while weaker arguments exerted minimal influence (Wood et al., 1985). However, when prior knowledge is low, those cues also assert an influence on attitudes (Petty & Cacioppo, 1986b). Conversely, individuals with limited prior knowledge exhibited a greater propensity to be influenced by message length (Wood et al., 1985).

Mood

Inducing a positive affective state in participants prior to exposure to persuasive communication has been demonstrated to increase the likelihood of attitude change in numerous studies (Biggers & Pryor, 1982; McGuire, 1985b). This assumption models a direct effect of mood, such as a positive mood effect on attitude change (Petty et al., 1993). Furthermore, mood may influence thought processes in a manner that is biased towards information that is congruent with one's mood, with positive moods tending to bias thoughts in a favorable direction (Mackie & Worth, 1989). Such biased thinking was expected to occur predominantly when individuals are highly motivated to process a message (Petty & Cacioppo, 1979b). In two experiments, Petty et al. (1993) investigated the persuasive effect of a mood manipulation, which was induced through an imagination task or a television comedy (see Table 3). As expected, positive mood induction resulted in more favorable attitudes, demonstrating an indirect effect on thoughts and attitudes when the

likelihood of elaboration was high, such as for high NFC individuals or in a high involvement condition. Conversely, when the probability of information processing was low (low NFC or low involvement), positive mood exhibited a moderating effect on attitudes, though not on thoughts (Petty et al., 1993).

Sociodemographics

Research findings indicate that studies published prior to 1970 demonstrated a greater influenceability among participants that could be attributed to gender (Eagly, 1978). However, meta-analyses also have shown a tendency for women to be more influentable than men (Cooper, 1979; Eagly & Carli, 1981). As demonstrated by Eagly and Carli (1981) in a sample of 148 conformity and persuasion experiments, subjects' gender accounted for approximately 1% of the variation in subjects' persuasibility and conformity. This phenomenon may be attributable to heightened societal conformity expectations for women, as evidenced in conformity experiments with group situations where the persuader is male or men and women have surveillance over each other's behavior (Eagly & Carli, 1981; Eagly & Wood, 1991). However, as Briñol and Petty (2005) have noted, gender differences might be negligible once other factors, such as the gender of the source and knowledge differences, are controlled. The influence of women may be amplified when their attitudes are less pronounced or their knowledge of the subject matter is limited, while the influence of men may be enhanced when women have more knowledge or stronger attitudes, particularly in subjects with which they have more knowledge or stronger attitudes (Cacioppo & Petty, 1980; Eagly & Carli, 1981).

The effect of age of respondents on persuasibility has also been a subject of considerable research (Krosnick & Alwin, 1989; Sears, 1983; Tyler & Schuller, 1991). A recurring finding in these investigations is that younger individuals exhibit a heightened propensity to be influenced in comparison to older adults. These results have been explained by the impressionable years model, which posits that individuals in this age group possess a particularly high degree of openness to change (Ceci & Bruck, 1993; Krosnick & Alwin, 1989). Furthermore, from the perspective of lifelong openness, individuals may exhibit susceptibility to attitude change throughout their entire lifespan (Alwin, 1994; Tyler & Schuller, 1991). However, evidence also suggests that both younger and older adults are similarly susceptible to persuasive influence (Visser & Krosnick, 1998). Concurrently, attitudes have been shown to evolve into increased stability with age, with older adults presenting heightened consistency over time (Alwin et al., 1991). In accordance with the

viewpoints of other researchers, it is proposed that these variations are not solely attributable to the effect of age. Rather, it is hypothesized that factors associated with age, such as increased knowledge, more stable social roles, and exposure to fewer attitude challenges, contribute to enhanced resistance in middle-aged individuals (Cacioppo et al., 1996; Tyler & Schuller, 1991).

Message characteristics

Message effects theories play a pivotal role in the field of persuasion research, offering a systematic understanding of how and why messages influence attitudes and behaviors (Cappella, 2006). In contrast to simple message testing, these theories facilitate the identification of the key features of a message responsible for persuasion, thereby enabling more efficient and effective communication strategies (Cappella, 2006). According to Petty and Wegener (1998a), message characteristics encompass elements such as the impact of argument quality and message framing on message elaboration. Furthermore, the influence of framing of messages as theoretical perspective on attitude formation can be considered as essential in this regard (Entman, 1993).

Argument quality

The Elaboration Likelihood Model (ELM) conceptualizes arguments as pivotal components of information that influence an individual's subjective evaluation of an advocated position (Petty & Cacioppo, 1986a, 1986b) (see also chapter 3.2.1). Therefore, it is posited that the persuasive impact of *argument quality* on attitude change occurs through the central route of processing (Petty & Cacioppo, 1986a, 1986b). Furthermore, the ELM suggests that when individuals possess both high motivation and the capacity to process a message, they engage in a process of deep cognitive elaboration, during which they systematically evaluate the strength of the arguments presented (Petty & Cacioppo, 1986a, 1986b). In this context, it was hypothesized that strong arguments — those that generate predominantly favorable thoughts—are expected to lead to positive attitude change, while weak arguments — those producing unfavorable thoughts — may result in negative attitude change or resistance (boomerang effect) (Petty & Cacioppo, 1986a, 1986b). Conversely, under conditions of low motivation or ability, persuasion occurs via the peripheral route, where the quality of the argument exerts a diminished influence, and attitudes are influenced by heuristic cues such as message length or source credibility (Petty & Cacioppo, 1986a, 1986b). However, the extent to which argument quality

influences persuasion is contingent on factors such as personal relevance and individuals' need for cognition (NFC) (Petty & Cacioppo, 1986a, 1986b). This relationship was evidenced in studies by Petty and colleagues, who found that when a message had high personal relevance, individuals' attitudes were primarily influenced by the quality of the arguments presented. By contrast, in circumstances where the message exhibited minimal personal relevance, individuals demonstrated a heightened tendency to be influenced by the expertise of the source rather than by the content of the arguments themselves (Petty et al., 1981; Petty et al., 1983).

Aside from the effect quality of arguments, the *quantity of arguments* has been expressed as essential for message processing, suggesting that increasing the number of message arguments results in higher elaboration (Petty & Cacioppo, 1984). In a study by Petty and Cacioppo (1984), the number of arguments was manipulated, with a message containing either three or nine arguments, while controlling for the personal relevance of the issue of university exams. The results of this study showed that the number of arguments exerted a more significant influence on attitude under low involvement, while argument quality showed minimal influence. However, when participants exhibited a high degree of involvement in the issue, argument quality elicited a stronger influence than issue-relevant arguments (see Table 3). These effects were interpreted in the sense that under high motivation, the arguments were elaborated extensively, while under low motivation, the number of arguments served as a peripheral cue (Petty & Cacioppo, 1984). Evidence has demonstrated that this direction of elaboration is applicable to other message variables, including message length (Wood et al., 1985).

Message matching

It has been shown that message matching to the presumed functional basis of attitude, or messages that match the underlying base of the attitude, has a higher effectiveness than messages that mismatch the underlying attitude base (Petty & Wegener, 1998b). Such a proposition stems from the notion that message matching has the potential to influence recipients' evaluations of the arguments presented in the messages (Petty & Wegener, 1998b). In the case of matched messages, recipients are more likely to hold favorable opinions, a phenomenon that is particularly pronounced under conditions of high elaboration likelihood (Chaiken & Maheswaran, 1994; Lavine & Snyder, 1996). For instance, matching messages are often perceived as more relevant to their recipients' self-images compared to messages that do not match (DeBono & Packer, 1991). However, the

matching effect may also be possible as a cue under low elaboration likelihood, such as when a product is image related (Chaiken, 1987).

Furthermore, the effect of message matching depends on whether individuals' attitudes are based on values and the central merit of things (low self-monitors) or based on social adjustment concerns (high self-monitors) (DeBono & Packer, 1991). In their (1998b) study, Petty and Wegener varied message matching concerning the functional basis of respondents attitudes and argument quality which were given to low or high self-monitors. They found that when message content aligned with respondents' product-related attitudes, particularly when image-based messages were presented to high self-monitors and quality-based messages were presented to low monitors, the persuasive impact of the message was amplified compared to scenarios where message content was not aligned. Moreover, when message content did not align with the functional basis of product attitudes, the effect of argument strength was diminished. This was evident when quality messages were presented to high self-monitors or image messages were presented to low self-monitors (Petty & Wegener, 1998b). Additionally, the interplay between argument quality and message congruency was discernible among individuals with low need for cognition. Thus, this interaction resulted in the baseline level of information processing being low, thereby determining whether matched messages were thoroughly scrutinized (Petty & Wegener, 1998b).

Message framing

Message framing effects refer to the manner in which attitudes are influenced by the structural design of a message (Entman, 1993; D. A. Scheufele, 1999). For example, the use of "fear appeals," which are defined as appeals that aim to elicit negative emotions, has been empirically demonstrated to enhance persuasion, as for example evidenced by the findings of Boster and Mongeau (1984). By underscoring specific aspects of emerging technologies, such as its benefits versus its risks, media frames have the potential to guide individuals' evaluation of the issue and the subsequent decisions they make in relation to it (Donk et al., 2011; Marks et al., 2007). When studying framing effects in communication research, researchers often focus on understanding how the presentation of information (the frame) influences individuals' perceptions, judgments, and behaviors (Chong & Druckman, 2007; Entman, 1993).

Importantly, the distinction between media frames and individual frames has been a subject of scholarly discourse (see for example D. A. Scheufele, 1999). *Media frames*,

in this context, refer to the attributes of news media that organize the presentation of events (Entman, 1991, 1993; Gamson & Modigliani, 1989). According to Entman (1993), the function of frames is “to select some aspects of a perceived reality and make them more salient²⁸ in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation.” (p.52). The salience of issues or the “ease in which instances or associations could be brought to mind” (Tversky & Kahneman, 1973, p. 208), has been described as essential in this process. In addition, the salience of frames is influenced by their accessibility from memory (Hastie & Park, 1986). In the context of media frames, studies have examined how journalists frame news stories, while other studies have explored the influence of media frames on audience perceptions of specific issues (D. A. Scheufele, 1999). Moreover, *individual frames* have been conceptualized as information-processing schemata of individuals or “mentally stored clusters of ideas that guide individuals’ processing of information”²⁹ (Entman, 1993, p. 53). Consequently, research studies evaluated how audiences construct meanings of frames or how individual frames impact individuals’ perception of the issue (D. A. Scheufele, 1999).

D.A. Scheufele's (1999) model of framing, which comprises three fundamental processes, can be regarded as a comprehensive framework for understanding the influence of media frames on public discourse. The initial process, *frame building*, pertains to the formation of these frames, taking into account the professional standards of journalists, the organizational routines that inform their work, and the external pressures exerted by political actors or interest groups. Journalists actively construct frames based on ideological perspectives, personal attitudes, and external constraints. Subsequently, the second process, *frame setting*, refers to the manner in which media frames influence the prominence of issue attributes in public discourse. According to D. A. Scheufele (1999), this phenomenon is similar to the concept of agenda-setting (McCombs & Shaw, 1972), wherein frames shape how individuals perceive issues by emphasizing certain aspects over others. However, agenda setting has been attributed to the salience of issues, while frame setting, or second-level agenda setting (see for example McCombs et al., 1997), has been related to the salience of issue attributes. Finally, the examination of *individual-*

²⁸ Salience refers to making a piece of information more noticeable, meaningful, or memorable to audiences (Entman, 1993).

²⁹ Cognitive oriented framing approaches will be discussed in detail in chapter 4.2.

level effects seeks to elucidate the manner in which media frames exert influence on cognitive aspects such as attitudes and behaviors (D. A. Scheufele, 1999).

However, as D. A. Scheufele (1999) has noted, the effects of media framing on individuals' reactions have focused on inputs and outputs, such as linking thematic frames to attitudes (for example Iyengar, 1991) without considering how audiences adopt to media frames. In this regard, the discussion has centered on whether the perceived importance of specific frames, rather than their salience among audiences, is the more essential factor in the framing of attitudes process³⁰ (T. E. Nelson et al., 1997). With regard to the various forms of framing, the distinction has been drawn between emphasis framing, in which topic-relevant information is highlighted, and equivalence framing or the distinction of valence framing, which for example involves the presentation of gains and losses in a balanced manner (Chong & Druckman, 2007; Druckman, 2001a; Tversky & Kahneman, 1987).

Emphasis framing

Emphasis framing has been described as an essential framing technique, focusing on how different aspects of an issue are highlighted or downplayed within a message, potentially featuring qualitatively different facts and opinions (Entman, 1993). Therefore, emphasis framing allows for shifts in the content and perspective of the message, influencing which aspects of an issue the audience finds most salient (Druckman, 2001b). Rucker et al. (2008) employed a meta-cognitive approach to message sidedness and found that acknowledging opposing viewpoints, without altering message content, enhanced confidence in one's attitudes and their influence on behavior. The rational of emerging technologies has been associated with benefits, as well as with their risky nature and negative effects, related to the fear of misuse (Hornig, 1990). Consequently, messages can emphasize risks to the environment or public health concerns (Myers et al., 2012). Furthermore, the framing of a message to align with audiences' ideology can positively impact attitudes. For instance, an economic-oriented frame for a climate change mitigation message targeting conservatives or a moral nature protection oriented frame for a message targeting liberals (Dixon et al., 2017).

³⁰ The perceived importance of frames has been described as involving a more deliberate process of evaluating and prioritizing information than salience (T. E. Nelson et al., 1997; D. A. Scheufele, 1999). This distinction between salience and perceived importance as conceptual dimensions was confirmed by T. E. Nelson et al. (1997), who demonstrated in their study that the impact of perceived importance on framing effects proved to be greater, whereas the accessibility of frames exerted a comparatively lesser influence.

Equivalence framing

According to the theoretical framework of *equivalence framing* (or also *equivalency framing*) (Druckman, 2001a), it represents communication technique that involves the presentation of “different, but logically equivalent, phrases cause individuals to alter their preferences” (Chong & Druckman, 2007, p. 114). This approach demonstrates how the manner in which information is presented — whether emphasizing a "glass half-full" or "glass half-empty" perspective — can significantly influence people's perceptions and decisions, even when the underlying facts remain unchanged (Levin et al., 1998). Therefore, the employment of valence framing in equivalence framing is particularly evident in the use of *gain and loss framing* (O’Keefe & Jensen, 2006). Gain frames, which present information with a positive outlook, are typically used to encourage actions or decisions by highlighting potential benefits. Conversely, loss frames emphasize the negative consequences of inaction or alternative choices, often leading to more cautious or risk-averse behavior (O’Keefe & Jensen, 2006).

A substantial body of literature has emerged on valence framing, with various scholars emphasizing different aspects of the concept (see Levin et al., 1998). A particularly salient type of valence framing is that of *risky choice framing*, which is employed as a concept of decision-making under uncertainty (Tversky & Kahneman, 1981). The initial documentation of the effect of risky choice frames was by Tversky and Kahneman (1981) in the "Asian disease problem," where individuals exhibited heightened risk aversion when options were presented positively, e.g., lives saved, and risk seeking when framed negatively, e.g., lives lost. Prospect theory posits that this phenomenon transpires due to individuals' propensity to evaluate outcomes in relation to a reference point (Kahneman & Tversky, 1979). Specifically, the subjective value function is concave for gains, leading to risk aversion, and convex for losses, promoting risk-taking. This means that people tend to take risks when presented with options to avoid losses rather than options with chances to realize gains (Tversky & Kahneman, 1981). While the risky choice effect was generally described as consistent, variability exists based on message manipulations of risk tasks and subject variables (Kühberger, 1998; Levin et al., 1998).

Another form of valence framing is *attribute framing*, in which certain attributes of an object or situation are emphasized in either a positive or negative light (Levin et al., 1998). Contrary to the notion of risky choice framing, which pertains to the selection of independent options, attribute framing influences assessments concerning a specific attribute without necessarily introducing risk. For instance, the description of a product as

"90% fat-free" tends to elicit a more favorable perception compared to framing it as "10% fat," despite the fact that both statements are factually equivalent (Levin et al., 1998). Attribute framing emphasizes evaluation, as opposed to decision-making between independent choices. As such, the dependent measure is typically a rating on a favorability scale or a yes/no judgment (Levin et al., 1998). These effects have been referred to as a valence-consistent shift, signifying that positively framed attributes result in more favorable evaluations compared to negatively framed ones (Levin et al., 1998). However, it has been noted that for issues with strongly held attitudes or high personal involvement attribute framing effects are less likely to occur (Marteau, 1989).

Goal framing is a concept that demonstrates the significant influence that the manner in which an action is framed has on decision-making and behavior (Levin et al., 1998). Accordingly, goal framing³¹ is predicated on the notion of a framing effect, whereby a situation or behavior is presented in terms of either the attainment of a positive outcome (gain frame) or the avoidance of a negative outcome (loss frame) (O'Keefe & Jensen, 2007). For example, the statement "Exercising will improve your health," provides the gains of performing this action, while a loss frame highlights the negative consequences of inaction: "Not exercising will harm your health." This phenomenon, known as goal framing or gain and loss framing, has emerged as a prevalent strategy in persuasive messaging, particularly in health communication, consumer behavior, and social dilemmas (O'Keefe & Jensen, 2007). Therefore, it is frequently employed in studies to ascertain which type of framing exerts a more substantial persuasive influence (Levin et al., 1998; O'Keefe & Jensen, 2006). Concerning the persuasive potential of the both types of framing, there has been concluded that they have a comparable influence on attitudes, however some studies indicated that loss framing exerted a stronger influence on behavior than gain framing (Kühberger, 1998; Levin et al., 1998; O'Keefe & Jensen, 2006; O'Keefe & Jensen, 2007). For example, Meyerowitz and Chaiken (1987) demonstrated that women exhibited a heightened propensity to engage in breast self-examinations when the potential repercussions of neglecting this practice were articulated in a negative context, in contrast to the positive portrayal of its consequences.

³¹ Bilandzic et al. (2017) further elaborated on this concept by introducing gain-positive versus gain-negative frames and loss-positive versus loss-negative frames to underscore the nuanced ways in which even positively or negatively framed information can be presented with either an optimistic or pessimistic tone.

In the field of persuasion literature, it has been established that positive and negative messages are processed differently (Smith & Petty, 1996). Negatively framed messages are expected to be processed more carefully because they are more attention-grabbing (Ditto & Lopez, 1992). This occurrence may be explained by the violation of people's expectancies when negative messages are received (Baker & Petty, 1994; Maheswaran & Chaiken, 1991). Empirical support has indicated that negative frames are more persuasive than positive ones, especially under conditions of high involvement. However, under low involvement, the efficacy of positive frames is heightened by the cue effect and the positive associations inherent within the message (Maheswaran & Meyers-Levy, 1990).

In a study by Smith and Petty (1996), message valence (positive or negative) and argument quality (weak or strong) were systematically manipulated in a message encouraging increased recycling (see Table 3). When the message was framed positively, participants demonstrated a higher level of agreement with weak and strong arguments. Conversely, when the message was framed negatively, respondents exhibited a greater propensity to agree with the message when it contained strong arguments (Smith & Petty, 1996). In a second experiment concerning responses to vitamin D consumption, the researchers investigated the additional influence of message expectancy with need for cognitions as additional moderator variable (Smith & Petty, 1996). It was evident that message framing had a greater effect when messages were framed in an unexpected way, when positive information was anticipated by individuals with low NFC, negative messages with strong arguments showed greater message processing than positive messages. However, when positive information was presented, low NFC participants exhibited equal agreement with strong and weak arguments (Smith & Petty, 1996). In contrast, when participants anticipated a negative message, low NFC participants demonstrated equal agreement with weak and strong arguments, while for positive messages, they exhibited stronger agreement with strong than weak arguments (Smith & Petty, 1996). These interaction effects were discussed in the context of message framing serving multiple roles as a variable, because under low elaboration likelihood, message framing functions as a peripheral cue, while under high elaboration likelihood, it functions as an agreement cue (Maheswaran & Meyers-Levy, 1990; Smith & Petty, 1996).

Visual presentation

It is imperative to acknowledge that the concept of framing in media extends beyond mere linguistic choices; it is also encompassed by the use of visual framing, which includes images, colors, typography, and video elements (Borah, 2009; Messaris & Abraham, 2001). For instance, investigations by Hardin et al. showed that photographs of athletes in newspapers and magazines exhibited gender disparity manifesting in the utilization of disparate poses, camera angles, and the portrayal of males in leadership roles, thereby reinforcing prevailing stereotypes (Hardin, Chance, et al., 2002; Hardin, Lynn, et al., 2002). Furthermore, the use of images in news stories, particularly those depicting the consequences of natural disasters, has been observed to provoke emotional reactions that shape attitudes towards the issues they address (Iyengar, 1991). As proposed in the "pictorial superiority effect," pictures show superior recognition relative to verbal messages (D. L. Nelson et al., 1976). However, as for example Geise and Baden (2015) have discussed, the majority of framing literature has focused on the effects of textual or linguistic framing devices rather than on visual framing elements. In integrating framing and visual communication³² approaches, the analysis of multimodal³³ framing effects and their influence on audience cognitions has been proposed in the literature (e.g., Brantner et al., 2011; Coleman, 2010; Geise & Baden, 2015).

Essentially, information processing in this realm contains the selective perception and structuring of information, its semantic decoding, the construction of meaningful relations between detected elements, and their integration into coherent meaning (Geise & Baden, 2015). Studies in the field of persuasion have demonstrated that individuals tend to engage with advertisements that employ visual highlights, with the visual appeal of these advertisements primarily exerting its influence as a peripheral cue under conditions of low issue involvement (Petty et al., 1981; Petty et al., 1983). This tendency may be attributed to the heightened applicability of visual elements, such as infographics, to the reader, thereby enhancing the degree of elaboration (Trumbo, 1999). A study by Gibson and Zillmann (2000) (see Table 3) demonstrated that visual framing exerts a substantial influence on risk perception. Specifically, the incorporation of images of ticks,

³² Visual communication can be summarized under comprising mediation and information exchange processes of semantic content that utilize visual phenomena, as such occurring in the media as pictures (Müller, 2007).

³³ Multimodality was referred to as interaction of meaning coded in different modalities such as sound, image, text or sign types such as typography, design, color, particular in a media context (Kress & van Leeuwen, 2001).

particularly in conjunction with images of child victims, led to an elevated assessment of the overall risk of contracting the disease by respondents. Moreover, when the victim images were not ethnically balanced (i.e., all White or all Black), respondents exhibited an exaggerated perception of the risk for children of the depicted ethnicity (Gibson & Zillmann, 2000). For the presentation of one-sided images, such as those depicting impoverished farmers or accidents in public parks, it has been observed to provoke biased audience assessments, a phenomenon that persisted for up to ten days (Zillmann et al., 1999). Conversely, the presentation of balanced visuals has been shown to mitigate this effect (Zillmann et al., 1999).

In the context of multimodal framing effects of text and visuals, it has been demonstrated that images can enhance persuasive efficacy by influencing the dominant cognitive responses elicited by the images (Coleman, 2010). The congruency between the message in the picture and the verbal information determines memory activation in both the verbal and visual memory subsystems (Powell et al., 2015; Seo & Dillard, 2019). However, congruency effects are also dependent on message valence. For example, positive verbal framing that is congruent with the visual presentation has shown to require less cognitive processing effort (J. Lee & Cho, 2022) and was associated with more supportive evaluations than non-congruent conditions (Seo & Dillard, 2019).

Source credibility

It is also relevant to consider the source of a message, as this factor has been shown to play a crucial role in the persuasion process. Early research on source credibility can be traced back to the studies of Hovland and Weiss (1951), who introduced the concept of messages with high or low credibility, depending on the source. Subsequent research by Hovland, Janis, and Kelley's (1953) demonstrated that when a message is attributed to a source with high expertise and trustworthiness, individuals are more likely to be persuaded. Conversely, messages from sources perceived as less credible tend to be less effective in changing attitudes (Hovland et al., 1953). In the field of persuasion, credibility has been defined as comprising the two principal dimensions³⁴ of expertise and trustworthiness of the communicator (Hovland et al., 1953). In contrast, McCroskey and Jenson

³⁴ Aside from the most common dimensions of expertise and trustworthiness, goodwill has been identified as a factor of credibility derived from Aristotle's ethical communication theory, which posits the communicator should be compassionate and empathic toward audience members' needs (McCroskey & Teven, 1999).

(1975) proposed a multidimensional measurement comprising the dimensions of character, sociability, composure, extroversion, and competence. Other factor analytical conceptions of source credibility have also placed emphasis on characteristics of presentation style or appearance of the source, relating to the subdimensions of dynamism, attractiveness, and likability (Berlo et al., 1969; Eisend, 2006; McGuire, 1985a; Ohanian, 1990).

Expertise

Expertise as dimension of source credibility refers to the perceived knowledge and competence of the source regarding the topic of the message, or the „extent to which a communicator is perceived to be a source of valid assertions“ (Hovland et al., 1953, p. 21). Experts are generally regarded as credible communicators (Petty & Wegener, 1998a), according to research in the persuasion context, messages from expert sources are more effective in altering attitudes compared to those from sources perceived as less credible (Chaiken et al., 1989; Petty & Cacioppo, 1986b). However, when acting as a peripheral cue, highly expert sources showed to led to higher attitude change than inexperienced sources when the topic presented is of low rather than high in personal relevance (Petty et al., 1981). Other moderating variables to the source effect include distraction (Harkins & Petty, 1981) and topic knowledge (Wood & Kallgren, 1988).

In a subsequent study, Heesacker et al. (1983) manipulated the field-dependence³⁵ or the differentiation of stimuli of participants, the quality of the arguments presented to the participants, and the source expertise. The arguments, in this case, were either presented by a Princeton professor or a local high school student. An interaction between expertise and argument quality was demonstrated, particularly among field-dependent subjects. For these subjects, strong arguments were more persuasive when presented by an expert, while weak arguments were less persuasive when presented by the expert. In contrast, field-independent subjects exhibited a main effect for argument quality, indicating that their persuasion was predominantly influenced by the strength of the arguments rather than the expertise of the source. This finding was interpreted as field-independent individuals engaging in more profound message processing, irrespective of the source's expertise (Heesacker et al., 1983).

³⁵ Field dependence has been related to participants to be influenced by the given context of self-reproduced cues, such as the social group (Witkin & Goodenough, 1977).

Trustworthiness

The second component of credibility, *trustworthiness*, concerns the source's perceived honesty and reliability ("degree of confidence in the communicator's intent to communicate the assertions he considers most valid") (Hovland et al., 1953, p. 21). In this sense, credible sources that are perceived as trustworthy are more persuasive than sources perceived as untrustworthy (Eagly et al., 1978). One explanation for this mechanism is that the function of trustworthiness as a peripheral cue or heuristic of validity to the source to not further warrant message processing for further reasons (Petty & Wegener, 1998a; Priester & Petty, 1995). Additionally, trustworthy sources are more readily accepted in situations involving low cognitive demand compared to untrustworthy sources, which require more message processing by individuals with low need for cognition (Priester & Petty, 1995).

Attractiveness and likability

McGuire's (1985b) Source Attractiveness Model expanded the understanding of persuasive communication by underscoring the significance of source attractiveness, likability, similarity, and familiarity as pivotal factors that amplify persuasive effectiveness. Among the dimensions of source attractiveness, the *physical attractiveness* of the source relates to the overall perception of the source's appearance (McGuire, 1985b). *Likability* encompasses the source's capacity to establish a personal connection with the audience, engendering a favorable impression (McGuire, 1985b). Furthermore, *similarity* involves the extent to which the source shares common characteristics or experiences with the consumer, while *familiarity* relates to the consumer's knowledge of the endorser (McGuire, 1985b).

Individuals are more inclined to be persuaded by sources they find attractive or relatable because these sources elicit favorable emotional responses and increase the likelihood of message acceptance (Chaiken, 1980; Puckett et al., 1983). Source attractiveness functions as a heuristic cue, prompting individuals to favor the message based on positive feelings toward the source rather than a thorough evaluation of the message content (Chaiken, 1980; Puckett et al., 1983). In a similar vein to the concepts of source expertise and trustworthiness, the effects of source attractiveness and likeability are more pronounced in situations where elaboration likelihood is low as opposed to high (Puckett et al., 1983). This phenomenon is exemplified by circumstances where the relevance of the topic is low (Chaiken, 1980; Petty et al., 1983), or when individuals possess limited

relevant knowledge (Wood & Kallgren, 1988). However, individuals high in self-monitoring may also exhibit a higher level of message processing when encountering an attractive source as opposed to an expert one (DeBono & Harnish, 1988).

In study by Puckett et al. (1983) (see also Table 3) participants were presented with essays on the subject of whether comprehensive exams should be a requirement for a bachelor's degree. A diverse array of authors was attributed with the essays, showcasing a range of social attractiveness and the quality of their respective arguments. Furthermore, the age of the author was a factor that was manipulated; however, this manipulation had no effect on the author's ability to persuade. However, the study's key finding was an interaction between social attractiveness and argument quality (Puckett et al., 1983). Specifically, it was found that individuals were more likely to process strong arguments more thoroughly and to agree with them when the source was considered attractive. Conversely, weak arguments from attractive sources led to a decrease in agreement, which was an unexpected result. Nevertheless, the influence of the source has been shown to be evident when elaboration likelihood was moderate or ambiguous (Puckett et al., 1983).

Demographic variables

Demographic variables related to the source, such as gender, age, and ethnicity, have been proven to serve multiple functions, thereby affecting credibility factors (Petty & Wegener, 1998a). With respect to the *gender* of the source, studies have identified a compelling gender bias, for example indicating that scientific articles with male author names are perceived as more credible by students than those with female names (Goldberg, 1968; Miller, J., D. & McReynolds, 1973)³⁶. Contrary to this, other studies have identified a bias in favor of female sources with regard to credibility, particularly in terms of trustworthiness (Pearson, 1982; Widgery, 1974). Addressing this subject, Petty and Wegener (1998a) proposed that the gender of the source functioned as a persuasion cue under low scrutiny, while men were regarded as more knowledgeable on the subject. However, under conditions of heightened scrutiny, it can be hypothesized that the gender of the source exerts a significant influence on the extent to which the information presented in the article is processed with bias, manifesting in a tendency to favor the perspective of the author whose gender aligns with the topic (Petty & Wegener, 1998a). As indicated in the study's

³⁶ However, this effect was also field dependent, as men received higher ratings for traditional masculine typed research fields such as law and city planning, whereas the effect was non-significant for women and feminine typed fields (dietetics and education) (Goldberg, 1968).

replication of gender bias, the mean discrepancy in ratings between male and female sources was negligible, and further influenced by situational factors such as the social status of the person, the composition of the sample (i.e., both female and male participants) as well as the context of the stimuli (Basow, 1986; Swim et al., 1989).

Source age as a salient factor in the perception of individuals has also been demonstrated to be associated with the perceived level of credibility. For instance, in media reporting, age is believed to activate positive or negative schemata of expertise and trustworthiness (Edström, 2018; Weibel et al., 2008). Negative age stereotypes, such as the association with lower qualifications and less potential for development (e.g. Kite & Johnson, 1988), have been reported to predict intentions for discriminatory behavior, as evidenced in the workplace (Chiu et al., 2001; Rupp et al., 2006). Nevertheless, older individuals are also regarded as possessing a depth of experience, reliability, and knowledge (Finkelstein et al., 2000; Hummert et al., 1998). Furthermore, studies examining the influence of the source's race revealed that, for Caucasian recipients, African American or Hispanic sources were processed more frequently than the same information presented by a Caucasian source which was attributed to an implicit negative attitude toward these groups (P. H. White & Harkins, 1994).

The sleeper effect of source credibility

First described by Hovland et al. (1949), the sleeper effect offers a unique perspective on the dynamics of source credibility over time. This phenomenon illustrates how a message from a source lacking credibility can become more persuasive as the source's credibility diminishes over time. Subsequent studies examined the effects of Army propaganda films on the opinions of U.S. soldiers during World War II (Hovland et al., 1949). By measuring opinions five days and nine weeks after film viewing, the authors found that the discrepancy between those who had seen the film and those who had not was more pronounced after nine weeks (Hovland et al., 1949). This delayed persuasion effect was attributed to a substantial increase in persuasion within the experimental group over time (Hovland et al., 1949).

To demonstrate the sleeper effect further, Hovland et al. (1953; 1951) conducted a series of experiments in which participants received messages from either trustworthy or untrustworthy sources. The findings indicated that messages originating from credible sources induced a more pronounced initial persuasion effect, indicating that individuals were more inclined to modify their opinions or accurately recall the message content and

source when the message was perceived as originating from a trustworthy source (Hovland et al., 1953). Therefore, messages from highly credible sources are initially more persuasive than those from less credible sources. However, over time, the memory of the source's credibility may diminish, leading individuals to focus more on the content of the message itself (Hovland et al., 1953). As such, communication associated with a discounting cue, such as an untrustworthy source, results in less persuasion immediately after exposure than later in time (Kumkale & Albarracín, 2004). The influence of messages from credible sources decreased over time, while the impact of messages from non-credible sources either remained constant or exhibited a slight increase (Kumkale & Albarracín, 2004). Notwithstanding this decline, participants in experiments were still able to recall the noncredible sources in subsequent assessments (Kumkale & Albarracín, 2004).

This observation prompted Hovland and Weiss to propose the dissociation hypothesis, which posits that the sleeper effect does not necessitate complete forgetting of the source. Rather, it occurs as a result of a weakened connection between the source and the message (Hovland & Weiss, 1951). As the source becomes less associated with the message over time, persuasion may increase if the message itself remains memorable (Hovland & Weiss, 1951). The retention of message content is facilitated by factors such as the credibility, attractiveness, and authority of the communicator (Hovland & Weiss, 1951). However, experimental investigations have been questioning the reliability and validity of the sleeper effect, failing to find such an effect and placing more emphasis on the study of situational conditions (T. Cook et al., 1979; Gillig & Greenwald, 1974).

In order for the sleeper effect to manifest, the persuasion literature identified the role of cues presented before or after message exposure³⁷, which was expected to be influenced by the motivation and ability to process the message (Pratkanis et al., 1988; Priester et al., 1999). For example, Priester et al. (1999) employed a discounting cue after message arguments and found that the sleeper effect occurred only for those recipients who were highly motivated to think about the message (high need for cognition). As evidenced in a meta-analysis by Kumkale et al. (2004), the average sleeper effect was small to moderate ($d = 0.25$) in conditions of higher ability and motivation. In conditions where the discounting cue preceded the message, the sleeper effect was observed to be weaker,

³⁷ According to Kumkale and Albarracín (2004), the original study by Hovland and Weiss (1951) used the discounting cue along with the message arguments, on the same stimulus page, thus it cannot be determined in this case whether the discounting cue was presented before or after message exposure.

which was attributed to resistance processes such as biased processing of the persuasive arguments (Kumkale & Albarracín, 2004). Conversely, when the cue was presented subsequent to the message, the persuasive effect was potentially amplified, resulting in a primacy effect of the message content (Pratkanis et al., 1988).

Table 3. Overview on effects of variables in persuasion studies

Study	Context	Experimental manipulation	Summary
Petty et al. (1981)	University policy	2 (issue involvement: high or low) x 2 (argument quality: strong or weak) x 2 (source expertise: high or low)	Greater effect of argument quality under high than low involvement Greater effect of source cue under low than high involvement
Petty, Cacioppo & Schumann (1983)	Product: edge razor	2 (issue involvement: high or low) x 2 (argument quality: strong or weak) x 2 (cue: celebrity or non-celebrity status)	Greater effect of argument quality under high than low involvement Greater effect of source cue under low than high involvement
Wood et al. (1985)	Preservation of the environment	2 (argument quality: strong or weak) x 2 (message length: long or short)	Higher knowledge related to more resistance to counter attitudinal appeal More prior knowledge related to better evaluation of message arguments (strong arguments) than less extent of prior knowledge Low prior knowledge interacted with message length
Petty & Wegener (1998)	Products: shampoo, coat, shoe, toothpaste	2 (functional match: match or mismatch) x 2 (argument quality: strong or weak) x 2 (self-monitoring: low or high) (Experiment 1) NFC (low or high) as additional factor in Experiment 2	Effect of argument strength was greater when the message content matched the functional base of product attitudes than when the message content mismatched the functional base Interaction between argument strength and functional match of attitude basis for respondents low in NFC
Tormala & Petty (2001)	Person behavior	2 (instruction: memory-based or on-line) Need to evaluate (high or low) Need for cognition (high or low)	Individuals with a high need to evaluate formed attitudes spontaneously and online Individuals with low need to evaluate relied more on memory-based processing
Rucker et al. (2008)	Products: cordless telephone, bike, toothpaste, DVD player, pain reliever	2 (message frame: one-sided, two-sided) X 2 (degree of negativity: none, slight)	Two-sided message framing of an issue led to attitudes held with greater certainty (Experiments 1–4) and attitudes that were more likely to influence behavioral intentions (Experiment 5) Framing effect for individuals high in NFC on attitude certainty (Experiment 4). Participants' thoughts about undisclosed negative information mediated the effect between framing and attitude certainty
Petty & Cacioppo (1984)	University policy	2 (issue involvement: high or low) x 2 (argument quality: strong or weak) x 2 (number of arguments: three or nine)	Influence of argument quality under high than low involvement Influence of the number of arguments under low than high involvement

3. Theoretical Perspectives on Attitude Formation

Petty et al. (1993)	Inducing mood by recalling positive life events (Exp. 1) or watching television program commercial (Exp. 2)	2 (mood: neutral or positive) x 2 (argument quality: strong or weak) x 2 (NFC: low or high) (Experiment 1) 2 (mood: neutral or positive) x 2 (argument quality: strong or weak) x 2 (issue involvement: low or high)	Positive mood led to more favorable attitudes Positive mood under high elaboration likelihood (NFC, involvement) influenced thoughts and attitudes Positive mood under low elaboration (NFC, involvement) influenced attitudes
Smith & Petty (1996)	Recycling, Vitamin D	2 (message framing: positive or negative) x 2 (argument quality: strong or weak) (Experiment 1) 2 (message framing: positive or negative) x 2 (argument quality: strong or weak) x (2 message expectancy: positive or negative)	Positive framed message interacted with weak and strong arguments Negative framed message interacted with strong arguments (Experiment 1) When low NFC individuals expected a positive message, the negative framed message was processed more extensively, agreed more with strong arguments, for positive message agreed equally with strong and weak arguments When participants expected a negative message, for a negative message, low NFC participants equally agreed with weak and strong arguments, for positive message agreed more with strong than weak arguments (Experiment 2)
Gibson & Zillman (2000)	Ticks disease	4 (pictorial exemplars (none, ticks only, ticks plus victims of Whites and Blacks, Whites only, and Blacks only)	The images of ticks, in conjunction with images of child victims, led to an elevated assessment of the overall risk of contracting the disease by respondents When the victim images were not ethnically balanced higher perception of the risk for children of the depicted ethnicity
Matheswaran & Meyers-Levy (1990)	Health risk: heart disease	2 (issue involvement: high or low) x 2 (message framing: positive or negative)	Positively framed messages more persuasive when there was little emphasis on detailed processing (low involvement) Negatively framed messages more persuasive when detailed processing occurred (high involvement)
Puckett et al. (1983)	University policy	2 (age essay author: young or old) x 2 (social attractiveness author: unattractive or attractive) x 2 (argument quality: strong or weak) x photograph author Control: Argument quality without author description	Attractive sources increased persuasiveness compared to unattractive sources when strong arguments were presented Attractive compared to unattractive sources reduced persuasiveness when weak arguments were presented No age stereotype effect

3. Theoretical Perspectives on Attitude Formation

Heesacker et al. (1984)	University policy	2 (source credibility: high or low) x 2 (argument quality: strong or weak) x 2 (field dependence: field dependent or field independent)	Effect of argument quality for field independent subjects Experts presenting strong arguments more persuasive Experts presenting weak arguments less persuasive Subjects who were low in differentiation of stimuli (field-dependent) showed different levels of persuasion from strong and weak arguments presented by a highly credible source
Priester et al. (1999)	University policy	2 (discounting cue: yes or no) x 2 (need for cognition: high or low)	Effect of discounting cue on initial persuasion, not as persuaded with cue as without cue at time 1 Presence of a discounting cue led to a sleeper effect for high elaboration likelihood (NFC) participants

3.2.3 Resistance to Persuasion and Counteracting Strategies

As described by Tormala and Rucker (2004), resistance to persuasion, or why persuasive attempts fail, can occur as a result of zero attitude change³⁸, reduced attitude change, or reversed attitude change ("boomerang effect"). The resulting alterations can be conceptualized along a spectrum, with one extreme representing maximal acceptance, characterized by a complete shift in attitudes toward the advocated position, and the other extreme representing maximal boomerang, characterized by a complete shift in attitudes away from the advocated position (Petty & Wegener, 1998a). *Acceptance processes* are those that move individuals toward the intended position, while rejection or *resistance processes* help individuals push back against the message (Petty & Wegener, 1998a). Motives to resist persuasion or to defend one's stance against attack can be subsumed under *reactance* or *resistance processes* (J. W. Brehm, 1966). Accordingly, psychological reactance is "the motivational state that is hypothesized to occur when a freedom is eliminated or threatened with elimination" (S. S. Brehm & Brehm, 1981, p. 37).

Furthermore, the conditions under which resistance processes occur may be attributed to either resistance motives or message processing strategies (Petty & Cacioppo, 1986a; Tormala & Rucker, 2004). To resist persuasion, strategies³⁹ can be summarized

³⁸ However, Tormala and Rucker (2004) also noted that zero attitude change may also result from failure in message processing, in this instance not being interrelated with resistance processes (see also Hovland et al. (1953).

³⁹ Zuwerink Jacks and Cameron (2003) further suggested counterarguing, attitude bolstering, message distortion, social validation, source derogation, negative affect, and selective exposure as strategies for resisting attitude change.

under the types of avoidance strategies, contesting strategies, empowerment strategies, and biased processing strategies (Fransen et al., 2015). In what follows, the reviews by Fransen et al. (2015) and Zuwerink Jacks and Cameron (2003) are used as a basis for assessing relevant counter persuasive strategies and motivations, summarized in Table 4 to be discussed against the backdrop of motivations for persuasion resistance derived from broader theoretical concepts from social psychological research.

Table 4. Strategies and motivation for the resistance to persuasion

Strategy	Motivation	Explanation
<i>Avoidance</i>	Cognitive avoidance	Ignoring commercial messages
	Physical avoidance	Avoiding advertising section
	Mechanical avoidance	Switch channels of programming (zapping)
	Selective exposure	Attitude-consistent exposure to online news articles
<i>Contesting</i>	Negative affect	Induced anger message on binge-drinking
	Counterarguing	Forewarning of persuasive intent leads to disagreement
	Source derogation	Looking for evidence of the source having low expertise
	Derogating persuasive tactic	Activating persuasion knowledge about a persuasion agent
<i>Empowering</i>	Attitude bolstering	Strengthening the preexisting attitude rather than reconsidering one's stance
	Message distortion	Motivation to maintain favorable view and undermining conflicting information
	Self-assertion	Assuring oneself that nothing could change one's opinion
	Social-validation	Seeking validation from social cues, such as audience cues
<i>Biased processing</i>	Weighting impact	Increasing the weight given to attitude-consistent attributes
	Reducing impact	Generating inferences spontaneously to other attributes to resist negative information
	Optimism bias	Underestimating risk by arguing negative events are less prone to happen to oneself than to others

Own illustration based on Fransen et al. (2015) and Zuwerink Jacks and Cameron (2003)

Avoidance strategies

Avoidance as a strategy⁴⁰ (see Table 4) occurs prior to message exposure, such as in the marketing context, as evidenced by cognitive avoidance as in ignoring commercial messages, physical avoidance as in avoiding the advertising section, or mechanical avoidance as in changing TV channels ("zapping") (Knobloch-Westerwick, 2012; Speck & Elliott, 1997). Furthermore, research on selective exposure or selective attention to media has been devoted to effects of avoiding messages that contradict one's own beliefs by focusing on attitude-relevant online news articles (Knobloch-Westerwick & Meng, 2009). As proposed in cognitive dissonance theory (Festinger, 1957), individuals encounter psychological discomfort (dissonance) when they hold beliefs, attitudes, or behaviors that are in conflict. Such discomfort is aversive and compels individuals to actively seek its reduction.

Cognitive dissonance theory has been the subject of extensive academic research, particularly in contexts where individuals are prompted to act in ways that are incongruent with their prevailing attitudes, whereby they adjust their attitudes to match their behavior, perceiving their actions as reflecting their true beliefs (J. W. Brehm & Cohen, 1962). The seminal study Festinger and Carlsmith (1959) demonstrated this phenomenon in which participants performed a mundane peg-turning task and were then offered a monetary incentive of either \$1 or \$20 for providing a positive evaluation of the task. Remarkably, those who received the modest \$1 payment (insufficient justification) reported higher levels of task enjoyment than those who received the higher \$20 payment. This "reverse incentive" effect has been replicated in numerous subsequent studies (see for example Zanna & Cooper, 1974; Zimbardo et al., 1965).

However, since the assessment of resistance is typically conducted in relation to the position advocated in a particular message, it could be argued that reactions during or after message exposure are most relevant in this regard (Petty & Wegener, 1998a). To achieve dissonance reduction, individuals' information processing becomes biased, with a tendency to favor information and interpretations that are consistent with their existing beliefs (Brownstein, 2003). The dissonance reduction process can be initiated by modifying one of the conflicting elements (leading to a self-generated attitude change), by

⁴⁰ As Fransen et al. (2015) suggested, avoidance is used to anticipate an unwanted persuasion attempt, whereas contesting, biased processing and empowerment strategies are used to ultimately cope with the actual experience of the persuasion attempt.

introducing new thoughts that increase the consistency of the elements (bolstering), or by decreasing the importance of one of the conflicting elements (Simon et al., 1995).

Contesting strategies

Contesting strategies can be subdivided into mechanisms that contest the message, the source, or the persuasive strategies per se (see for example Fransen et al., 2015). Concerning *message reactance*, it was initially argued that the construct may not be measurable in empirical studies (S. S. Brehm & Brehm, 1981), but in later research, message reactance has been tested by assessing affective and/or cognitive reactions in recipients and by using self-report measures (see for example Dillard & Shen, 2005). This concerns, for example, the parallel processing of affective and cognitive processes to persuasive health messages, such as public service announcements, to influence attitudes and behavioral intentions (Dillard & Peck, 2000; Leventhal, 1970). In terms of message reactance, the intertwined model of reactance by Dillard and Shen (2005), in which reactance is conceptualized as consisting of anger and counterarguments, has received empirical support in a meta-analysis of reactance processes by Rains (2013). The first element in this framework is the induction of *negative affect*, such as anger, in response to threats to liberty, which can be evident when one's goal attainment is impeded (Nabi, 1999) to evoke reactions of attack and rejection (Dillard & Peck, 2000).

A second component of *counterarguing* as a cognitive response to persuasion was described as the exposure of individuals to a message resulting in cognitions that can be in agreement or disagreement with the message, for example induced by forewarning of the message's intent (Petty & Cacioppo, 1977, 1979b; Wright, 1975). As proposed in *Inoculation Theory* (McGuire, 1964; McGuire & Papageorgis, 1961), the exposure of an individual to a low-dose, attenuated version of a virus can facilitate the development of immunity, thereby enhancing the individual's ability to fight subsequent infections. Consequently, inoculation theory posits that the resistance to discrepant messages can be augmented by inoculating initial attitudes (McGuire & Papageorgis, 1961). It was shown that exposing individuals to minimal counter attitudinal information, followed by instruction in its refutation, increases their ability to resist persuasion (McGuire & Papageorgis, 1961). This process produces a mild threat to the prevailing attitude, prompts the development of arguments that strengthen their position, and thereby increases the resistance to future influence attempts (McGuire & Papageorgis, 1961). Inoculation can be attributed to message sidedness, for which two-sided messages have been shown to be more

effective than one-sided messages in the presence of counterarguments (Hovland et al., 1953). Protection Motivation Theory (PMT) developed by Rogers (1975, 1983), particularly in the context of fear appeals, aligns with expectancy-value principles, proposing that fear-based messages are most effective when they underscore the severity and likelihood of the threat (e.g., an earthquake). Moreover, in order to prevent the threat, the individual must have the ability to perform a behavior (self-efficacy). However, if the perceived threat is not seen to be manageable, individuals tend to resist the message in order to reduce fear (Mulilis & Lippa, 1990). Motivation and processing message content have been demonstrated to be associated with this phenomenon (Petty & Cacioppo, 1979a; Wood et al., 1995).

In addition to the content of the message, the source of persuasion can be contested which has been referred to as *source derogation* (Wright, 1973). This manifestation has been described as being more likely to occur under conditions of low elaboration likelihood, for example, when negative affect is attributed to the source, such as being perceived as biased and having less expertise or being less trustworthy (Tormala & Rucker, 2004; Wright, 1973). As delineated in the Persuasion Knowledge Model (PKM) developed by Friestad and Wright (1994), the reaction to persuasion is predicated on the beliefs concerning the persuasion attempt. In its original formulation, the concept was denoted as the "schema of persuasion," thereby signifying the mobilization of persuasion-related cognitive faculties in the aftermath of persuasive endeavors. Notably, this domain has received scant attention in models of consumer research and attitude change (Friestad & Wright, 1994; Wright, 1986). Accordingly, persuasion knowledge is developed from social interactions, observing persuasion agents such as marketers and from news media (Friestad & Wright, 1994).

As shown in Figure 12, the Persuasion Knowledge Model (PKM) distinguished between *targets* of persuasion to whom a *persuasion attempt* is made, such as consumers, and *agents* that a target identifies as responsible for designing a persuasion attempt, such as a company⁴¹ (Friestad & Wright, 1994). Such strategic behavior on the part of the agent is described as a persuasion attempt, which can be attributed to the content of the message and the manner in which it was designed and delivered to influence the recipient's beliefs, attitudes, or behaviors (Friestad & Wright, 1994). In response to the persuasion attempt, consumers react by employing persuasion coping behavior strategies, which includes

⁴¹ However, it is possible for individuals to shift roles and perspectives during the course of an interaction as a consumer attempts to bargain or otherwise influence a target's behavior (Friestad & Wright, 1994).

cognitive and physical actions during a persuasion episode and thinking about the agents persuasion attempt, which includes knowledge-based expectations and memory of features of persuasion attempts to be activated (Friestad & Wright, 1994).

In the context of consumer coping behaviors, three distinct knowledge structures emerge as persuasion outcomes (Friestad & Wright, 1994). The first key element is *persuasion knowledge*⁴² (see Figure 12), referring to schemas like functions which enable respondents to recognize, remember, analyze, and interpret persuasive attempts and to select and use appropriate coping attacks derived from situational knowledge (Friestad & Wright, 1994). Additionally, persuasion knowledge encompasses the evaluation of messages or products, as well as inferences concerning the agent or the overarching topic of persuasion or marketing (Friestad & Wright, 1994). Consumers, in their attempts to navigate the complex landscape of persuasive strategies, often pursue a multifaceted array of intertwined objectives. These goals may include the management of long-term relationships with marketers, the enhancement of understanding regarding advertising tactics, and the conservation of cognitive resources (Friestad & Wright, 1994). Additionally, consumers may endeavor to influence how others perceive their expertise in the domain of persuasion and consumers endeavor to uphold a favorable self-image (Friestad & Wright, 1994).

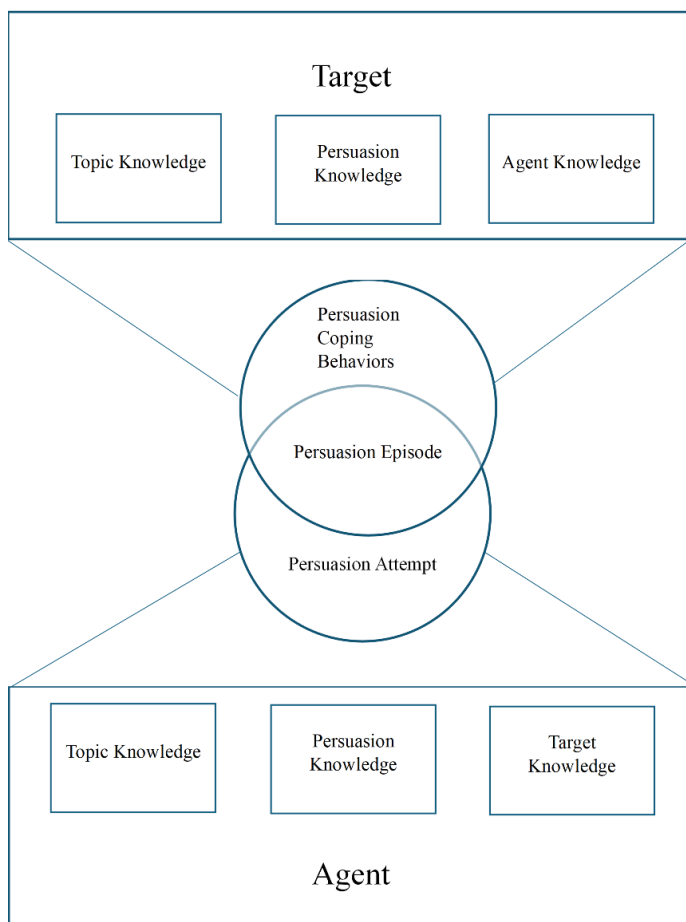
Besides persuasion knowledge, as depicted in Figure 12, *agent knowledge* or *topic knowledge* may be activated during a persuasion episode. As individuals are expected to hold valid attitudes toward a given topic (Chaiken, 1987; Petty & Cacioppo, 1986b), several factors have been identified as affecting tactics' motivation to seek valid attitudes about the perceived agent. For example, the persuasive competence of the agent or their personality traits may be evaluated (Friestad & Wright, 1994). The identification of persuasion tactics employed by the agent has been conceptualized within the framework of the *change-of-meaning principle* (Friestad & Wright, 1994). Understanding an agent's actions as a form of persuasion significantly changes the interpretation of the message conveyed. Such recognition elicits a variety of consumer responses, including disengagement, distraction, and evaluative judgments (Friestad & Wright, 1994). These cognitive responses can diminish the persuasive power of the communication and influence future

⁴² Overall, persuasion knowledge encompasses a wide range of psychological phenomena, including their underlying causes and consequences, their perceived significance, the extent to which individuals can regulate their psychological responses, the temporal progression of the persuasion process, and the effectiveness and appropriateness of persuasion tactics (Friestad & Wright, 1994).

attitudes toward the marketer (Friestad & Wright, 1994). Consequently, this process not only disrupts the immediate message but also shapes how consumers interpret and respond to subsequent persuasion attempts over time (Friestad & Wright, 1994).

However, as Friestad and Wright (1994) remarked, research settings where participants' persuasion knowledge is suppressed or misdirected may not produce findings that generalize well to real-world contexts, where people actively recognize and use their persuasion knowledge. By focusing only on single-message designs, researchers may overlook how audiences respond to varying levels of persuasion transparency. Within-subject designs, though often avoided in persuasion research because of priming effects to message features, are particularly useful in the context of persuasion knowledge because they allow researchers to observe how individuals recognize, compare, and respond to different persuasive tactics, providing insights into how persuasion knowledge operates in everyday decision-making (Friestad & Wright, 1994).

Figure 12. The Persuasion Knowledge Model



Own illustration based on Friestad and Wright (1994)

Empowerment strategies

In the reduction of dissonance, *attitude bolstering* with information can be utilized as a strategy for the defensive support of attitudes by means of the generation of thoughts that are consistent with and supportive of one's original attitude, without direct refutation of message arguments (Abelson, 1959; Lydon et al., 1988; Sherman & Gorkin, 1980). According to Festinger's (1957) theory of cognitive dissonance, the introduction of new cognitive elements is used in reducing dissonance. Consequently, attitude reinforcement is presumed to occur in circumstances involving elevated processing demands (Sherman & Gorkin, 1980).

Another related strategy of message processing in favor of initial attitude is *message distortion*, or *biased assimilation*, in which a message is selectively processed to reflect one's initial attitude (Festinger, 1957; Kunda, 1990). As proposed by the concept of *motivated reasoning* (Kruglanski, 1989b; Kunda, 1990), the validity of information should be consistent with a preferred judgment conclusion (preference-consistent information) than of information that is inconsistent with a preferred judgment conclusion (preference-inconsistent information) (Ditto et al., 1998). According to Kunda (1990), individuals engage in a biased memory search to support their desired conclusions, selectively recalling evidence that validates their beliefs while undermining conflicting information. However, the phenomenon of motivated reasoning is constrained by the need to maintain an "illusion of objectivity," meaning that individuals will only accept conclusions that they can justify as reasonable (Kunda, 1990). An alternative perspective, proposed by Ditto and Lopez (1992), suggests that the key difference lies in the amount of cognitive effort rather than its direction. Research findings indicated that negative or contradictory information prompts more systematic and detailed processing because it requires critical evaluation, whereas preferred information is more readily accepted with minimal scrutiny (Pratto & John, 1991; Taylor, 1991).

However, other individuals who share the initial attitude may also be used as a reference point, a phenomenon described as the "*social validation function*" (Festinger, 1950, 1954).

As individuals seek to validate their initial opinions, they may employ various strategies, including reassurances or *self-assertions*, to convince themselves and others of the stability of their views (Zuwerink Jacks & Cameron, 2003). These self-control mechanisms can be related to increased persuasion under effortful processing, for example when strong arguments are involved (Burkley, 2008).

Biased processing

To this end, biased processing strategies have been shown to distort or dismiss the impact of persuasive messages. By this, it is meant that the mental representation of the decision environment is restructured to favor one alternative before a choice is made (Brownstein, 2003). The implications of unwanted information can be evaluated by *weighting their impact*, therefore the negative information is accepted because it cannot be refuted by biased assimilation (Abelson, 1959; Festinger, 1957). By increasing the weight assigned to attitude-consistent attributes, dissonant cognitions are inherently reduced, also see attitude bolstering (Abelson, 1959). Another strategy of biased processing relates to *reducing impact*, which was described as relevant in terms of generating inferences spontaneously, while committed individuals are expected to resist negative information and minimize the effect of this information on other attributes (Ahluwalia, 2000). This phenomenon was found, for example, when consumers read information about product attributes and are likely to make inferences about other related attributes (D. H. Lee & Olshavsky, 1995). Furthermore, as evidenced by the notion of *optimism bias*, or the difference between a person's expectation and the subsequent outcome (Sharot, 2011), negative occurrences are anticipated to be less likely to be experienced by oneself than by others (Sharot, 2011; Weinstein, 1987). In the specific context of health beliefs, for instance, individuals may underestimate their risk of developing lung cancer by downplaying the perceived threat posed by factors such as their personal family history of cancer (Weinstein, 1987).

In general, attitudes are more resistant to attack when they are accessible (see for example Fazio, 1995), thus when more issue-relevant processing occurs (Krosnick & Petty, 1995). This is the case because a high level of message elaboration leads to a greater influence of an initial message on final judgments (primacy effect), whereas a low level of message-relevant elaboration leads to a greater influence of a second message on final judgments (recency effect) (Haugtvedt & Wegener, 1994). A strong initial attitude is particularly effective at resisting a subsequent message when that message can be counter-argued, such as when it presents weak or inconsistent arguments against the initial attitude (Wu & Shaffer, 1987). Moreover, findings by Haugtvedt and Wegener (1994), for example, indicate that individuals who pay more attention to an initial message due to its high personal relevance are less influenced by a subsequent counter-message. Conversely, individuals with low personal relevance exhibited an increased susceptibility to the persuasive impact of the second message. Furthermore, participants in the high relevance

condition exhibited a tendency to formulate a greater number of counterarguments against the opposing message (Haugtvedt & Wegener, 1994).

3.3 Attitude Formation in the Context of this Work

Starting from the *three-component model* of attitude in affective, cognitive, and behavioral dimensions (see for example Katz, 1960; Ostrom, 1969; M. J. Rosenberg & Hovland, 1960), for this dissertation the *cognitive response* perspective (Katz, 1960) of attitudes is considered as particularly relevant (see chapter 3.1.1), which in the persuasion context has been reduced by the predominant cognitive process of elaboration or the degree of thinking about the attributes of an attitude object (Petty & Cacioppo, 1981, 1986a). As indicated in theoretical papers in the field, the concepts of attitude formation, attitude change, and attitude reinforcement are utilized interchangeably with the term *attitude formation*, under the assumption that the persuasion process is reflected by attitude strength and accessibility (Cameron, 2009; Petty & Wegener, 1998a). Empirical discussions have been posited in support of the proposition that such models are better suited to explaining attitude formation than attitude change (Carpenter, 2015; M. A. Hamilton et al., 1993). This seems to hold significant value because the following empirical studies place emphasis on the cognitive processes involved in attitude formation within the framework of dual-process models.

As a means of identifying the direction of media effects and the variables to be proposed for subsequent empirical studies, a comparative discussion of theoretical models of the persuasion process seems warranted. A review of *dual-process-models* of attitude change (see chapter 3.2.1), such as the Elaboration Likelihood Model (ELM), Heuristic-Systematic Model (HSM), and the MODE Model (Chaiken, 1980; Fazio, 1990; Petty & Cacioppo, 1986b), reveals that the routes of information processing leading to attitude change are shaped by the multiple roles of variables (Chaiken, 1980; Petty & Wegener, 1998a). This perspective is relevant for underlining the conditions under which respondents engage in low or high information-processing effort. Dual-process models like the ELM (Petty & Cacioppo, 1986b) and HSM (Chaiken, 1980) are favored in this regard over the Unimodel of Persuasion (Kruglanski & Thompson, 1999), implying a single route of information processing, because in the context of science information processing, it has been acknowledged that people either use automatic, effortless thinking (heuristic/peripheral) or deliberate, effortful thinking (systematic/central) (Bode et al.,

2020; Nisbet et al., 2002), which is allowing for more precise predictions about how motivation, ability, and situational factors influence persuasion.

Furthermore, the Persuasion Knowledge Model (PKM) (Friestad & Wright, 1994) builds upon the notion of heuristics from the HSM by delving into the process through which individuals develop a comprehensive understanding of persuasion tactics. This facilitates individuals' ability to manage their own attitudes, assess persuasion agents, and apply their personal persuasion expertise. Such comprehensive, activated knowledge facilitates navigating and resisting influence attempts (Ahluwalia, 2000; Friestad & Wright, 1994). In comparison of memory based models and the Elaboration Likelihood Model (ELM), Matthes (2007b) stated that the ELM assumes that judgments are formed on-line, meaning individuals evaluate central or peripheral cues immediately, and these attitudes are later assessed. In contrast, memory-based models suggest that judgments are formed only when needed, based on recalled information rather than immediate evaluation (Hastie & Park, 1986). As Chong and Druckman (2007) have proposed, although the distinction between modifying the content of beliefs (persuasion) and altering the importance of those beliefs (framing) is analytically beneficial, referring to the expectancy value model (e. g. Ajzen & Fishbein, 1980), attitudes frequently consist of vague or ambivalent beliefs, and frames can introduce new considerations or highlight existing ones, also influencing overall attitudes⁴³. Following the perspective of Price et al. (1997) this work considers framing as a more indirect, persuasive influence that primes what people think about (B. Cohen, 1963), thereby activating affective states and evaluations.

The dimension of information processing is also proposed differently, as the ELM highlights that people either engage in deep, central processing when motivated and able or rely on peripheral cues and heuristics when motivation is low (Petty & Cacioppo, 1986b). Memory-based models, however, suggest that all available information—both central and peripheral—is considered at the time of judgment formation which make them concentrate on the time dimension of attitude processing, rather than being evaluating the type of information based on the employed cognitive effort (Hastie & Park, 1986). Consequently, it can be determined that the employment of an appropriate model, whether it

⁴³ It was also argued by Matthes (2007b) that the prevailing logic underpinning framing research is predominantly memory-based, a phenomenon that cannot be fully explained by two-process models. Moreover, framing approaches conspicuously lack consideration of heuristics, a crucial aspect that is central to the functionality of dual-process models (Matthes, 2007b).

be an online/memory-based model or a two-process model, is contingent upon the specific objectives of the research undertaking (Matthes, 2007b). In the context of this dissertation, the focus is on the cognitive effort or elaboration process undertaken by the respondents, which is proposed in the ELM as determined by motivation and ability to process the message (Petty & Cacioppo, 1986b; Priester et al., 1999).

Accordingly, the moderating role of individual variables on message-based and source-based effects on attitude formation was outlined with examples of experimental investigations (see chapter 3.2.2). In addition to message variables described in early persuasion frameworks, such as argument quality/quantity, and message matching with respondents' functional basis of attitudes (Petty & Cacioppo, 1984; Petty et al., 1981), message framing and processing plays an essential role, as outlined in the persuasion literature (Smith & Petty, 1996) as well as in the context of effects of media reporting (Borah, 2011). Nonetheless, some scholars have proposed that there is a distinction between framing and persuasion in terms of influence on attitudes (Chong & Druckman, 2007; T. E. Nelson & Oxley, 1999). The concept of framing pertains to the way one influences the salience or perceived importance of certain components of an attitude, such as emphasizing economic factors over environmental considerations when evaluating a housing project (Entman, 1993).

In addition to the aforementioned aspects of attitude formation, behavior change theories such as the Theory of Reasoned Action (TRA) (Ajzen, 1985) and the Theory of Planned Behavior (TPB) (Ajzen, 1991) were discussed. Frameworks such as the Technology Acceptance Model (TAM) (F. D. Davis, 1989) proposed perceived usefulness and ease of use as additional determinants of technology adoption. While this perspective may be considered somewhat limited in the context of media reporting on emerging technologies, the model has been employed in conjunction with specific technologies, such as hydrogen fuel (see Huijts et al., 2012). The focal point of this dissertation is the effect path of the relationship between attitudes and behavioral intentions and actual behavior (Ajzen, 1991).

As detailed in chapter 2.5, extant theoretical perspectives on science communication models of attitude formation have primarily focused on exploring the mechanisms through which scientific information is disseminated or exchanged from scientific actors to the public. These models have additionally focused on the societal perspectives from which this information can be viewed (Bucchi & Trench, 2021). Consequently, considerable progress has been witnessed in the formulation of models on reception and discourse

of scientific information by audiences. Illustrative of these modified models are the contextual model of science communication (Brossard & Lewenstein, 2009) and dialogue-oriented approaches (Trench, 2008). Trench (2008) concluded that all perspectives have a juxtaposition in science communication, with one-way dissemination models still applicable in contexts such as media coverage and public information campaigns, and two-way models suitable for public debates and long-term communication projects, including citizen science initiatives.

It has been described as imperative that models of science communication address not only individuals but also the collective concerns of social groups, recognizing that some communities may prioritize ethical, cultural, or environmental concerns over purely scientific facts (Akin & Scheufele, 2017). In this context, collective audience approaches have underscored the pivotal role of diverse publics in terms of their interest, engagement, values, concerns, and levels of understanding regarding scientific issues (Boyd, 2010; Holford et al., 2023). This transition towards audience-centric approaches (M. Burns & Medvecky, 2018) has been related to targeted media strategies such as agenda-setting and framing as crucial elements in enhancing the effectiveness of science communication (Bubela et al., 2009). Therefore, providing insights into the role of the media in shaping public perceptions and offering valuable tools for adapting communication to diverse audience segments and maximizing the impact of scientific messages (Donk et al., 2011; Nisbet & Mooney, 2007).

However, the perspective of direct media effects has been called into question, with a shift toward a more nuanced consideration of indirect media effects through cognitive mediation processes (McLeod et al., 2002). This view of indirect media effects has been deemed more applicable in the context of social controversial issues, such as emerging technologies, where individuals tend to react to scientific information in accordance with their “mental models,”⁴⁴ in which information is interpreted in light of existing beliefs (Bruine de Bruin & Bostrom, 2013). Yet, it has been commented in the literature that there is still a lack of integration of communication frameworks that model the audience's cognitive processes, such as information processing of scientific information. In the realm of science communication, recognizing these elements enables communicators to discern knowledge gaps and misconceptions, facilitating the implementation of

⁴⁴ Mental models refer here to a generic term to describe beliefs and values of audiences.

strategies such as framing, which aims to enhance the accessibility of information and promote optimal decision-making (National Academies of Sciences, Engineering, and Medicine, 2017; B. Scheufele & Scheufele, 2010). Consequently, the relevant information on which citizens rely on, for example, on the topic of nanotechnology, is derived from scientific experts or the media (D. A. Scheufele & Lewenstein, 2005). The literature distinguishes two perspectives in this regard, either some more informed collectives of citizens or interest groups who are informed by the media through facts, and the cognitive miser perspective, where audiences rely on simple heuristics to form their attitudes (D. A. Scheufele & Lewenstein, 2005).

It has been shown in previous theoretical reflections that the news media have a direct impact on attitudes towards science and technology, especially through news framing, but also an indirect impact due to the media's role as a source of information (Brossard & Nisbet, 2007; De Vreese et al., 2011). Furthermore, it has been noted in the literature that audience beliefs can serve as a filter to make sense of scientific information provided by the media (Brossard & Nisbet, 2007; Ho et al., 2008; D. A. Scheufele, 2006). From an audience-centric perspective, it has been stated that science information can be evaluated with either low or high processing effort, which has been related to the perspective of "cognitive misers" (Taylor, 1981). However, at other times, it is more adaptive to effortful processing of information (Priester et al., 1999). In essence, to investigate the formation of attitudes toward emerging technologies, experimental approaches are needed to test the components of the message or source and intervening factors to identify causal relationships, which will be the main focus of the following literature review.

4. Literature Overview on Media Effects regarding Emerging Technologies

Media plays a crucial role in modern society, serving as the primary conduit for information and communication, shaping public discourse, influencing opinions, and framing the way individuals perceive various aspects of life, including science and technology (Entman, 1993; McCombs & Shaw, 1972; Nisbet & Mooney, 2007). As for example Eveland and Cooper (2013) reviewed, certain media effects models assume uniformity in news coverage and its direct increase in the accuracy of beliefs. Nevertheless, for example D. A. Scheufele (1999) also noted that taking a closer look at these models, they encompass a broad range of media-based factors that influence public perception. To model these facets, related theories are agenda-setting, and framing which operate in distinct yet interconnected ways (D. A. Scheufele, 1999)⁴⁵. Specifically, the agenda-setting theory emphasizes audiences' interpretations of the importance attributed to issues (McCombs & Shaw, 1972). However, the perspective of direct media effects has been called into question, with a shift toward a more nuanced consideration of indirect media effects through cognitive mediation processes (McLeod et al., 2002).

The media framing approach, as defined by Entman (1993), involves a more sophisticated form of influence, shaping not only the presentation of an issue but also the aspects that are emphasized, thereby affecting how audiences interpret and understand it. The relationship between media use and attitudes toward science and technology has been a significant component of science communication research since the last decade, with studies emphasizing two stances of research regarding media reporting on emerging technologies (see for example Milde, 2017). One such area of research involves the identification of public discourse in the context of emerging technologies. This encompasses the analysis of media content and formats, including the identification of recurring patterns in media reporting for different technologies, while focus of this research lays mostly in the theoretical tradition of framing research, with a methodological focus on content analysis (Milde, 2017). Regarding the second research direction, the effects of news coverage on audience attitudes are mostly evaluated in the context of public survey research, and less often in an experimental context (Milde, 2017). In this vein, the aim for this dissertation is to illuminate causal relationships between variables, such as message framing or source credibility, and moderating variables, in order to predict attitudinal outcomes.

⁴⁵ For a more specific concept related debate in the mass communications literature on the distinctions among framing, priming, and agenda setting see for example Scheufele (2000) or McCombs (2004).

Accordingly, the role of media prioritization and agenda-setting in shaping public attitudes toward science and technology and recurring media framing will be reviewed in chapter 4.1. Moreover, the influence of framing on cognitive processing in audiences (Price & Tewksbury, 1997; Price et al., 1997) will be explained in chapter 4.2. Given that science communication audiences can be considered to employ mental shortcuts or heuristics in certain instances (Fiske & Taylor, 2017), several moderating variables to the media framing effect have been investigated (D. A. Scheufele & Lewenstein, 2005), which will be the subject of chapter 4.2.1. The empirical literature on experimental studies regarding message framing effects on the issue of emerging technologies will be summed up in chapter 4.2.2. Concurrently, the repercussions of the communicator's medium in a media reporting context will be delineated in chapter 4.2.3. Chapter 4.3 synthesizes the extant empirical literature.

4.1 Agenda Setting and Media Framing

Agenda-Setting theory posits a relation between the emphasis mass media places on issues and the importance attributed to these issues by audiences (McCombs & Shaw, 1972; D. A. Scheufele & Tewksbury, 2007). Therefore, agenda setting has been described as the study not of what media influence how people think, but of what they think about (B. Cohen, 1963). Thereby, two analytical levels of agenda-setting have been distinguished: first level agenda-setting is concerned with objects such as issues, while second level agenda-setting has been described as influencing cognitive and affective attributes (McCombs & Salma Ghanem, 2001; B. Scheufele, 2004).

As noted by several authors, the concept of agenda setting poses ambiguity when it comes to differentiating it from other salience-based theories of media effects (Cacciatore, Scheufele, & Iyengar, 2016; B. Scheufele, 2004). Agenda Setting has been disentangled by some authors as a global concept subsuming priming and framing (Ghanem, 1997; Takeshita, 1997), while other reviews have identified agenda setting as related to priming (B. Scheufele, 2004). Price et al. (1997) have argued that activation is the key mechanism connecting agenda-setting, priming, and framing. Priming, as defined within the cognitive accessibility model, refers to the heightened accessibility of specific ideas or issues in an individual's mind, attributable to their prominence in media content (Hastie & Park, 1986). For instance, the notion of availability heuristics draws on the assumption that judgments are not based on all relevant criteria, but rather on those that are accessible at the time (Iyengar & Kinder, 1987). In this regard, news accessibility effects have been

linked to issues that are more prominent in the minds of audience members. Agenda-setting and priming processes are utilized as benchmarks for evaluation, which could be regarded as a temporal extension of agenda-setting, with these considerations giving rise to judgments about issues (Iyengar & Kinder, 1987; D. A. Scheufele & Tewksbury, 2007). However, framing, in contrast, has been associated with applicability effects, emphasizing respondents' schema activation. Frames have been viewed as attributes of objects selected through framing processes (B. Scheufele & Scheufele, 2010). Therefore, the presence of a cognitive schema that matches the frame was expected to produce a framing effect (Cacciatore, Scheufele, & Iyengar, 2016).

A number of studies have highlighted agenda-setting dynamics in contemporary media landscapes, for example, Groves et al. (2016) analyzed science coverage in the Spanish digital press over the last decade using automated content analysis and found that between 6% and 7% of the news in the sample was science and technology related. In this study, the coverage of science issues, such as biomedicine, generally outpaced that of technology issues, however, a noticeable rise in technological content was observed, particularly in the latter half of the decade (Groves et al., 2016). Following the public discourse, the study of media reporting on emerging technologies has been related to nanotechnology (Anderson et al., 2005; Donk et al., 2011; Lewenstein et al., 2005), and a long research tradition can also be identified for the study of media reporting on biotechnology (Bonfadelli et al., 2002; Gaskell, 2004). Furthermore, media reporting on energy technologies, including nuclear power (Gamson & Modigliani, 1989), carbon capture and storage (van Alphen et al., 2007), and wind energy (Stephens et al., 2009) has been a subject of inquiry. Recent research has also focused on the patterns of media reporting concerning artificial intelligence (AI) and its applications (Nguyen & Hekman, 2024; Tandoc et al., 2025).

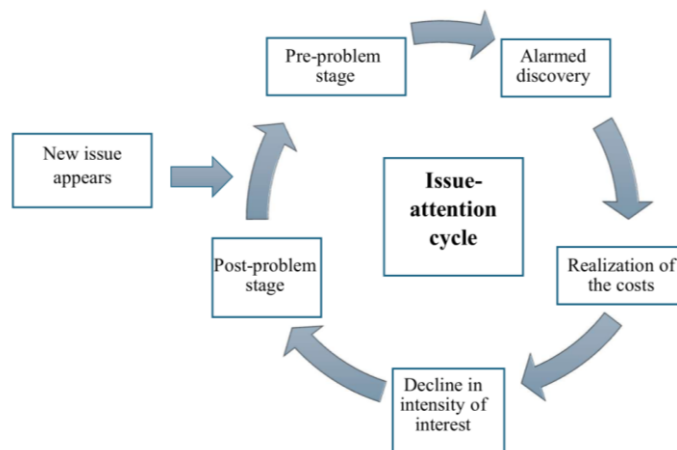
The prioritization of certain technologies in media reporting, which influences public support and understanding, has been attributed to the issue attention cycle approach, which suggests that issues or events follow cyclical patterns in media attention, which subsequently influences policy decisions (A. Downs, 1972; Weingart et al., 2000). For example, this effect was evident following the 2011 Fukushima accident and the subsequent media attention on the issue of nuclear power (Kepplinger & Lemke, 2016; Kristiansen, 2017). As described by A. Downs (1972), the issue-attention cycle has five stages. Initially, the "pre-problem stage" occurs after an issue is first mentioned in the news, as shown in Figure 13. In this phase, a societal issue is present; however, it has not

yet garnered significant public attention. Furthermore, the subsequent stage, characterized by the alarmed discovery and euphoric enthusiasm stage, is marked by the public's heightened awareness and sense of euphoric anticipation regarding the potential for societal resolution of the issue, often accompanied by the belief that a swift resolution is within reach⁴⁶. The third stage, the realization of costs of solving the problem considers the trade-off between high cost and low probability of success (A. Downs, 1972; K. K. Petersen, 2009). However, the gradual decline of intense public interest in the problem due to the realization of the difficulties in solving the problem, resulting in different public reactions such as discouragement, disinterest, or suppressing thoughts related to the problem (A. Downs, 1972). At this stage potentially other novel issues enter the public's interest (post-problem stage) (A. Downs, 1972).

To illustrate issue cycle patterns related to emerging technologies, Nisbet and Huge (2006) evaluated the political development of plant biotechnology, while also measuring its media attention through a content analysis of the New York Times and the Washington Post between 1978 and 2004. It was evident that media attention followed cyclical waves, from decades of relative invisibility until the triggering event of social protest in 1999, followed by a spike in media attention to the issue in 2000 caused by the StarLink affair related to the contamination of food products by StarLink corn, while the amount of media coverage was declining by then (Nisbet & Huge, 2006). For artificial intelligence (A.I.) Nguyen and Hekman (2024) reported that news content on A.I. has become significantly longer and more detailed, with articles increasing by about 39% from 2010 to 2020. The number of articles increased sharply until peaking in 2018 and then declined, suggesting a "hype cycle" similar to previous trends seen with big data (Nguyen & Hekman, 2024).

⁴⁶ However, A. Downs (1972) has acknowledged that the optimistic view of solving societal problems may be culturally biased, as the American tradition would emphasize that any obstacle can be overcome without reordering societal structures, which may differ from views in other cultures.

Figure 13. The issue-attention-cycle



Own illustration based on A. Downs (1972) and K. K. Petersen (2009)

Media framing refers to the influence that media frames or the way information is presented in news and other media have on individuals' perceptions, judgments, and behavior (D. A. Scheufele, 1999) (see chapter 3.2.2 for the theoretical distinction of media framing). According to Entman (1993), framing involves selecting certain aspects of a perceived reality and making them more salient in communication, which can influence how an issue is interpreted by the audience.

In the domain of news framing research, scholars have distinguished between generic and issue-specific frames (De Vreese, 2005). Generic frames, including conflict, human interest, economic consequences, morality, and responsibility, have been characterized as context-transcending and found across diverse subjects (Semetko & Valkenburg, 2000). In contrast, issue-specific framing refers to a specific issue (Matthes & Kohring, 2008), which provides a more detailed perspective on the issue of emerging technologies. As previously evaluated, some emphasis frames can be considered generic frames that can be related to a wide range of issues (Chong & Druckman, 2007). A further distinction can be made between episodic and thematic framing, with episodic framing focusing on individual instances and specific events, and thematic framing addressing broader trends and systemic issues, providing a more comprehensive view of an issue (Iyengar, 1991). Extensive research has been conducted on the coverage of political framing in technical controversies, with political and strategic framing focusing on the motivations or conflicts behind technological developments. For instance, framing that emphasizes the competition between stakeholders related to nuclear power rather than the

technology itself has been employed in media reporting (Gamson & Modigliani, 1989; Nisbet, 2009). Nevertheless, in disciplines such as health and risk communication, equivalence framing, the presentation of logically equivalent information such as valence framing and the subtypes of risky-choice framing, attribute framing, and goal framing, have been described as relevant (Levin et al., 1998). In particular, gain and loss framing remains dominant in research, although it has been noted that framing effects studies have predominantly tested single frames rather than examining how multiple or competing frames influence perceptions (Borah, 2011).

Recurring framing patterns of emerging technologies

Depending on the media narrative, focusing on specific aspects of a technology can have a differential influence on public perception (Cobb & Macoubrie, 2004). Recurring frames highlighted in the literature regarding the subject of emerging technologies (see for an overview Nisbet, 2009) are displayed in Figure 14. In the case of GMOs, for example, the framing has often been risk-oriented, with the media focusing on potential health and environmental risks, but also showing that medical aspects are often thematized in a more positive light than genetically modified foods (Eyck, 2005; Nisbet & Lewenstein, 2002). In contrast, the framing of artificial intelligence (AI) has been oriented towards benefits, highlighting its transformative potential across various sectors, with a focus on the content's country of origin as determined by the news outlet (Cools et al., 2022; Kong, 2019). A content analysis of news articles on AI and automation revealed that the contexts of work, arts, and education were the most prominent (Cools et al., 2022). Nguyen and Hekman (2024) identified four meta frames that dominated the AI news discourse, which were *AI & politics*, *AI & economics*, *AI & research/science*, and *AI in society & culture*. Over time, the news discourse has become more sensitive to risks, with 54.9% of articles referring to at least one type of data risk. A key theme in these discussions was the tension between the promise of AI, such as more accurate data insights, and concerns about privacy invasion (Nguyen & Hekman, 2024). Similarly, the benefits of automation were often juxtaposed with fears of diminished human influence, discrimination, and exclusion (Nguyen & Hekman, 2024). In this regard, Bunz and Braghieri (2022) highlighted a tendency in the media to portray AI systems as outperforming human expertise.

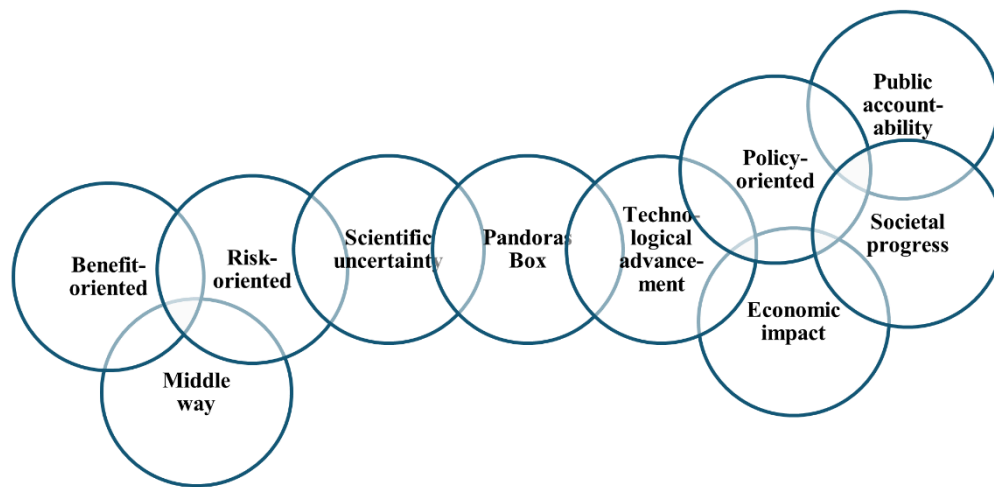
In a similar vein, renewable energies have generally been presented in an optimistic manner in the media, particularly with regard to their environmental benefits.

However, critical facets regarding economic costs and feasibility have also been observed (Djerf-Pierre et al., 2016; Rochyadi-Reetz et al., 2019). For the topic of nanotechnology, which can be associated with high complexity as well as a lack of actual experience of the general public with the technology, studies found predominantly benefit-oriented media framing, for example emphasizing medical and economic benefits of nanotechnology (Anderson et al., 2005; Donk et al., 2011). Using data from the 10 largest U.S. newspapers for 1999-2008, Weaver et al. (2009) identified four issue frames for stories about nanoscale science and technology, namely progress, regulation, conflict, and generic risk, while concluding that the progress and general risk frames particularly dominated early coverage of nanotechnology.

Furthermore, the literature identified prominent frames in science-related policy debates of emerging technologies such as for nuclear energy and the biotechnology discourse (Dahinden, 2002; Gamson & Modigliani, 1989). It was evident that nuclear power was framed in terms of economic development and social progress prior to 1970. However, following the media discourse shift up to 1986 with the Chernobyl incident, there was a demand for public accountability, and scientific uncertainty was expressed with reference to the unstable "Pandora's Box" or "runaway nature" of the technology (Friedman et al., 1992). The technology-specific narratives of *Pandora's box*, *Frankenstein's monster*, or *runaway science* framing have also been employed in the context of unforeseen consequences that AI may unleash (Bingaman et al., 2021).

Moreover, the *middle way or alternative path* framing has focused on finding a possible compromise position, such as in the context of alternative paths to energy independence and the use of solar, hydro, and wind power (Nisbet, 2009). Another exemplar of critical media discourse pertains to embryonic stem cell research, where the moral and ethical dimensions were accentuated, as illustrated by the employment of metaphors ("scientists are playing god") or catchphrases such as "respect for life" (Nisbet, 2009; Nisbet & Scheufele, 2007). By comparing the media framing of nanotechnology and biotechnology, Lewenstein et al. (2005) found that, for both technologies, most news articles emphasized progress and economic aspects. However, for nanotechnology, they observed a greater use of framing related to Pandora's Box, runaway, and public accountability. In addition, Nisbet and Huge (2006) have underscored a public engagement frame in the context of plant biotechnology, emphasizing public opinion results, public support, or awareness of the technology.

Figure 14. Overview of recurring media frames in the context of emerging technologies



Own illustration based on Nisbet (2009)

4.2 Media Effects

Explaining the psychological processes of framing has been the subject of extensive research (for example Chong & Druckman, 2007; Iyengar, 1991; Price & Tewksbury, 1997). In this context, the framing effect is an essential determinant to demonstrate how subtle changes in the presentation of information can activate different cognitive processes (Price & Tewksbury, 1997; Price et al., 1997). Accordingly, the way in which emerging technologies are framed-whether focusing on their benefits, risks, or ethical concerns-can shape public understanding and attitudes (Cobb, 2005; Druckman & Bolsen, 2011). In addition, from the perspective of the source of communication, it has been examined whether communicator characteristics, such as the deception of scientists in news articles, influence recipients' perceptions of the credibility of the source (Weibel et al., 2008; Yuan et al., 2019). Studies of public perceptions of the risks and benefits of nanotechnology have shown that respondents' beliefs that nanotechnology will have a positive impact on society are correlated with their knowledge about the technology, emotional reactions, and sociodemographic factors (Cobb & Macoubrie, 2004; Gaskell et al., 2005; C. Lee et al., 2005).

Framing effects have been described as primarily shaped by a memory-based judgment formation process⁴⁷ (Druckman & Nelson, 2003; T. E. Nelson & Willey, 2001; Shrum, 2004). This process has been contrasted with on-line judgment formation, where individuals initially access and report opinions based on information and do not use information from memory to form a judgment (Hastie & Park, 1986; Shrum, 2004). Tor-mala and Petty (2001) examined the process by which individuals form attitudes toward a hypothetical person based on described behaviors and found that individuals with a high need to evaluate formed attitudes spontaneously and online, whereas those with a low need to evaluate relied more on memory-based processing. This was supported by attitude-recall valence relations (Experiments 1 and 2) and response latency measures (Experiment 2). In addition to the need for evaluation, interest in a topic or the need for orientation in mass media have been shown to influence online judgments (Lavine, 2002; Matthes, 2006).

As an essential process, knowledge activation was described to be relevant in terms of framing effects, as proposed by the research of Price and Tewksbury (1997). Knowledge was considered to be built on the basis of the person's established knowledge store, which contains readily accessible information (Price & Tewksbury, 1997). Furthermore, whether how accessible the available knowledge is to be activated, those attributes with the highest excitation levels are used to make evaluations (Price & Tewksbury, 1997). The model of Price and Tewksbury (1997) further differentiated between applicability effects and accessibility effects in media influence. Applicability effects occur during news processing when certain attributes of a news story activate certain ideas, making them more likely to be used in evaluations. The model conceptualizes news story framing as an applicability effect, or first-order stimulus effect, in which the organization and structure of a message makes certain thoughts more relevant and likely to be used in judgments (Price & Tewksbury, 1997; Price et al., 1997). Price et al. (1997) discussed the concept of message framing as an *applicability effect*, which posits that the way a message is framed has a significant impact on the thoughts that become relevant and are used in evaluative processes. However, the activation of ideas is not exclusive-applicable ideas compete with other accessible thoughts, limiting what can be influenced at any given time

⁴⁷ However, the literature has been conflicted about the relevance of memory-based or on-line-based evaluations for framing effects, as in some cases judgments formed online have been considered irrelevant to the process of media framing effects (Druckman & Nelson, 2003) while it was also advocated for the inclusion of both processes in explaining attitude formation toward media effects (Matthes, 2007a).

(Price & Tewksbury, 1997). In contrast, *accessibility effects* refer to the persistent activation of these ideas as second-order effects of media messages, with activation potential based on temporary residual arousal (Iyengar, 1991).

Besides knowledge activation processes, the activation of schemata (see Fiske & Taylor, 2017) has been attributed to media framing effects (Matthes, 2004; B. Scheufele, 2003; B. Scheufele & Scheufele, 2010). One aspect is that schemata are relevant in the information processing process as data-driven schema identification is "bottom-up" in the sense that which schema is identified determines whether and how that information is understood and categorized (Crocker et al., 1984). Furthermore, once a schema has been identified, it controls the processing of incoming information and also the activation of linked schemas, corresponding to concept-driven information processing "top down" (Crocker et al., 1984). In the context of science communication, media frames often lead audiences to process information via the peripheral route, especially when the scientific content is complex and unfamiliar (D. A. Scheufele, 2006). This means that heuristic cues, such as the perceived trustworthiness of the scientist, the simplicity of the message, or the frequency of media coverage, often take precedence over in-depth analysis of the science itself (Bode et al., 2020; Chaiken, 1980).

4.2.1 Individual Determinants

Previous literature has expressed the importance of mental shortcuts, or heuristics, in how audiences evaluate scientific evidence (S. Chen & Chaiken, 1999; D. A. Scheufele, 2006; Tversky & Kahneman, 1975). In the case of controversial issues such as emerging technologies, this perspective may be particularly relevant, as the public can be considered to be rather uninformed and, from a "cognitive miser" perspective, tends to gather only as much information as necessary to make a decision, relying on mental shortcuts or heuristics (Fiske & Taylor, 2017; C. Lee et al., 2005). Important intervening variables which have been described in this regard are prior knowledge (D. A. Scheufele & Lewenstein, 2005), prior attitudes (see for example Druckman & Bolsen, 2011), trust or deference to science (for example Brossard & Nisbet, 2007), emotional reactions (for example Slovic et al., 2004), and information processing (Eveland & Cooper, 2013), which constituted the explanatory base for science communication effects models of attitude formation to be outlined in this subchapter.

Value predispositions

To theoretically model the relationship between variables on attitude formation a relative large body of studies in the political and science communication domain (see for example Besley & Shanahan, 2005; Brossard & Nisbet, 2007; Nisbet & Goidel, 2007) used Markus and Zajonc's (1985) Orientation–Stimulus–Orientation–Response (O–S–O–R) model, thereby extending the stimulus-response model to include initial orientations and changes in orientations brought about by media stimuli. An overview of the variables and components of the O-S-O-R model is given in Table 5. As articulated by Brossard and Nisbet (2007), the influential variables in the model were typically classified as "endogenous" variables, with the primary focus in theorizing and analysis being on the interrelationships among these factors, including their direct and indirect effects on the response or dependent variable of interest. Additionally, control variables or "exogenous variables", such as demographics (gender, age, education), were incorporated into the model.

In the O–S–O–R model, "O₁" is used to represent value predispositions that are long-term in nature, including ideology and deference to scientific authority (Brossard & Nisbet, 2007). The "S" component denotes the stimuli of media consumption, characterized by its application and attention across various types of news outlets and other information sources concerning scientific topics, such as biotechnology (Brossard & Nisbet, 2007). Moreover, "O₂" models the intervening orientations or behaviors between stimulus and outcome, such as knowledge about biotechnology, trust in sponsors, reservations about science in general, and schemas, for example, about specific applications of biotechnology (Brossard & Nisbet, 2007). The letter "R" is intended to represent the response or outcome of both sets of orientations and the communication stimuli, such as public evaluations of agricultural biotechnology or support for the technology.

Brossard and Nisbet (2007) empirically demonstrated that value predispositions in the model, such as deference to scientific authority, played a central role as an information short-cut for reaching judgments about agricultural biotechnology. This relationship was directly associated with support for the issue, but also indirectly related to support via trust in biotechnology sponsors and perceptions about its reservations about the impacts of science (Brossard & Nisbet, 2007). Another relationship that emerged pertained to the attention to media coverage of agricultural biotechnology, which was related to increased knowledge and, in turn, more support for the technology (Brossard & Nisbet, 2007). In a similar vein, Ho et al. (2008) examined the influence of value predispositions alongside information behavior and knowledge of public opinion on the stem cell debate

in the US. In total, value predispositions accounted for 20% of the explained variance in support for human embryonic stem cell research, which had a higher impact than that explained by attention to science news (2%) (Ho et al., 2008).

Furthermore, the study revealed a negative association between religiosity and support for embryonic stem cell research, while scientific authority was positively associated with support for this research (Ho et al., 2008). The influence of knowledge on support for embryonic stem cell research was also moderated by religiosity, ideology, and deference to scientific authority, showing that individuals with high deference to scientific authority were more influenced by levels of scientific knowledge than individuals showing low levels of this variable (Ho et al., 2008). Likewise, Brossard and Nisbet (2007) found in their study that deference to scientific authority was the strongest influence on support for agricultural biotechnology. Concerning other individual variables, Drummond and Fischhoff (2017) demonstrated, employing data from the nationally representative General Social Survey, that individuals with greater scientific knowledge and education were more likely to express polarized beliefs on the issue of stem cell research at that time than on the subject of genetically modified foods, which was considered less controversial on other grounds. Additionally, the overall level of trust in science was found to be associated with beliefs that were consistent with the scientific consensus (Drummond & Fischhoff, 2017).

Table 5. Orientation–Stimulus–Orientation–Response (O–S–O–R) model

Exogenous	Endogenous			
<i>Demographics and other controls</i>	<i>Orientation O_1</i>	<i>Stimulus S</i>	<i>Orientation O_2</i>	<i>Response R</i>
Age	Ideology	Diversity of information sources	Knowledge issue	Evaluations issue
Gender	Deference to scientific authority	Attention to news sources	Trust in sponsors	Support issue
Education			Reservations science	
Race			Schema issue	
Income				
Religion				

Own illustration based on Brossard and Nisbet (2007)

Knowledge as heuristic

Considering the relevance of the general premise of scientific literacy, Nisbet and Scheufele (2009) in their review pointed to the empirically weakly supported amount of variance that scientific knowledge has on attitude formation towards science issues (Allum et al., 2008), suggesting the influence of additional audience-related factors such as value predispositions (see for example Ho et al., 2008). *The Science Literacy and Heuristics Model (SLHM)* of attitude formation developed by D. A. Scheufele and Lewenstein (2005), offers an alternative framework for understanding how individuals process and respond to scientific information, particularly in cases where they lack extensive expertise in the subject matter.

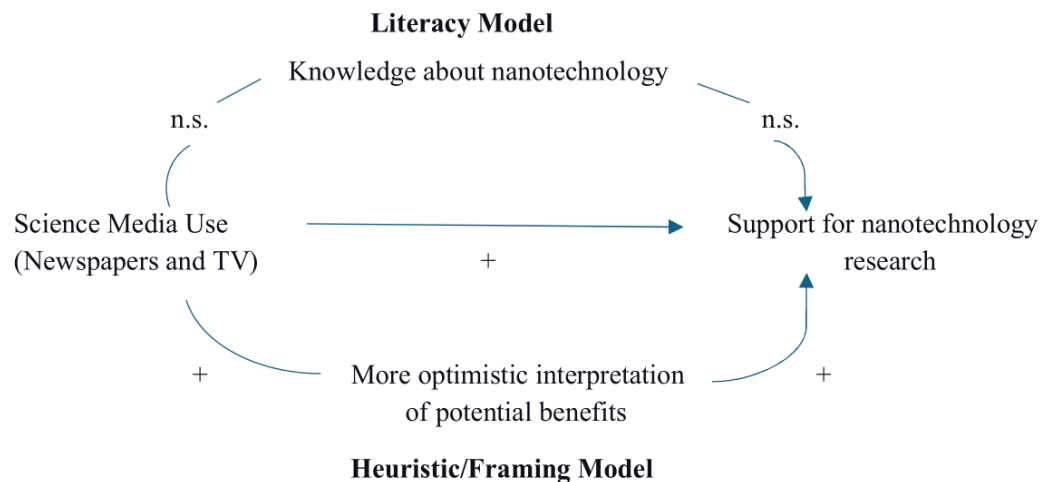
A central aspect of this model is the interplay between scientific literacy and heuristics. As discussed in chapter 2.5, scientific literacy refers to the level of knowledge an individual has about scientific concepts, processes, and the nature of science itself. This includes an understanding of scientific terminology, the scientific method, and the ability to critically evaluate scientific claims (Miller, J., D., 1983). Within the SLHM framework, scientific literacy stands as a critical facilitator of effective engagement with scientific content, a notion that assumes added importance when individuals encounter science-related information that is complex and challenging to comprehend (D. A. Scheufele & Lewenstein, 2005). However, even individuals with high scientific literacy may resort to heuristics when confronted with particularly complex or ambiguous information (Kahan et al., 2011). For individuals with lower scientific literacy, heuristics play a more prominent role in decision-making, as these shortcuts help them navigate scientific information that might otherwise be overwhelming or difficult to process (Leiserowitz, 2006). In order to test these assumptions, D. A. Scheufele and Lewenstein (2005) investigated whether scientific literacy or heuristics play a more important role in developing attitudes regarding nanotechnology by employing a national U.S. survey.

As shown in Figure 15, the degree to which individuals pay attention to mass media news sources, including newspapers, television, and online news outlets, emerged as a highly significant predictor of their attitude (support) toward nanotechnology (D. A. Scheufele & Lewenstein, 2005). The authors concluded that the scientific literacy perspective with learning effects through media information and increasing public support proved to be an inadequate explanation for the observed trends (D. A. Scheufele & Lewenstein, 2005). While knowledge about nanotechnology did not exert a substantial influence on public support when controlled for confounding variables such as demographics,

media consumption, and risk/benefit perceptions, the initial correlation between knowledge and support was deemed to be questionable (D. A. Scheufele & Lewenstein, 2005). This was primarily due to the likelihood that it was an artefact of a general scientific interest rather than a direct effect of knowledge. These results may be interpreted to suggest that media exposure influenced attitudes independently of knowledge, thereby indicating that framing played a more significant role than factual understanding. Given that media coverage at the time emphasized benefits, public support was more influenced by positive messaging than by actual literacy (D. A. Scheufele & Lewenstein, 2005). For example, at an early stage in the issue cycle of nanotechnology, attitudes were regarded as still evolving, thus rendering knowledge a weak predictor of support (D. A. Scheufele & Lewenstein, 2005).

However, the study also found support for the notion that respondents relied on heuristics, which were often shaped by mass media, to assess attitudes such as risks, benefits, and support of nanotechnology. As depicted in Figure 15, heavy users of science media coverage were seen as more supportive of nanotechnology, suggesting that the benefits of the technology outweigh the risks, which was associated with positive media framing of the technology. Additionally, Nisbet et al. (2002) investigated the influence of different media channels on attitudes towards science using cross-sectional survey data and found that the use of newspapers, science magazines and science television was associated with fewer reservations about science, while the use of television was associated with more reservations. In comparison to the study by D. A. Scheufele and Lewenstein (2005), the research by Nisbet et al. (2002) revealed, in addition to these direct effects of media information, but also that, at least for television consumption, there was a decrease in procedural (science as a process of inquiry) and factual science knowledge (J. Miller et al., 1997), which mediated the relationship of media use on the reservations about science, overall increasing reservations.

Figure 15. The Science Literacy and Heuristics Model (SLHM)



Own illustration based on D. A. Scheufele and Lewenstein (2005)

Influence of affect

The effectiveness of persuasive messages is contingent upon the cognitive responses they elicit, as well as the prior understanding of issues such as thoughts and counterarguments (Greenwald, 1968; Kruglanski, 1989a). In this regard, cognitive effects have been linked to individuals employing heuristics related to rationality and utility maximization, such as availability, representativeness, and anchoring, to make judgments (Kahneman et al., 1982; Tversky & Kahneman, 1974). However, decision research also recognized the relevance of emotions for judgment processes, with stimuli producing quick and easy reactions and perceptions due to affect (Epstein, 1994; Zajonc, 1980). Furthermore, the dual-process nature of affective reactions has been described as either systematic or heuristic processing of information (Epstein, 1994; Petty et al., 1993).

Decision-making based on feelings, known as the *affect heuristic*, has been extensively described in the literature (Finucane et al., 2000; Slovic et al., 2007). Rather than undertaking a thorough analysis of all aspects of a situation, people refer to their "affect pool," which contains emotional labels associated with objects, events, or ideas (Slovic et al., 2007). According to the affect heuristic, positive or negative labels are consciously or unconsciously associated with objects and, like other heuristics, are used as a cue to simplify judgments, especially when decision making is complex or resources are limited (Slovic et al., 2007). The affect heuristic has for example been tested in the context of decision-making concerning gambles and (eating) preferences (Slovic et al., 2007). However, with regard to science communication, studies on the effects of risk and benefit

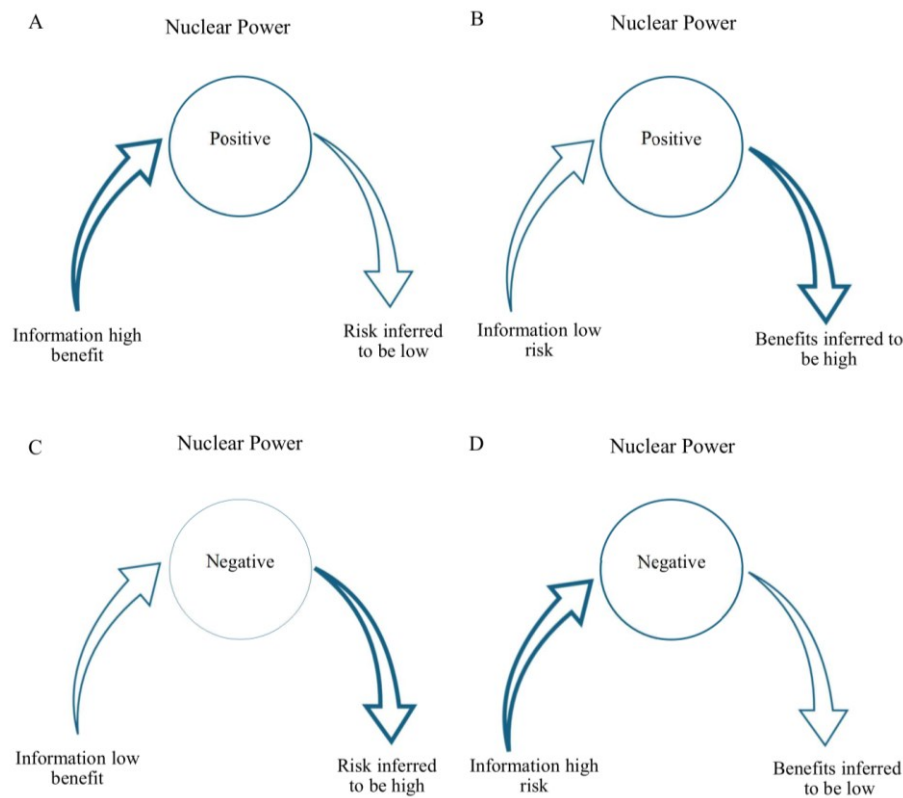
perceptions and the degree of dread can be considered most relevant (see for example Fischhoff et al., 1978).

Subsequent studies indicated a correlation between risk and benefit perceptions, suggesting that as the perceived benefit increased, the perceived risk decreased, and vice versa. As Slovic et al. (2007) have observed, for example, smoking and alcoholic beverages tended to be perceived as having very high risks and relatively low benefits, whereas vaccines and antibiotics tended to be perceived as having high benefits and relatively low risks. The positive or negative affect in turn was linked to the perceived benefit and risk. For example, for positive judgment of a technology, low risk and high benefit would be estimated (Alhakami & Slovic, 1994). Finucane et al. (2000) proposed the affect model, which posits that individuals rely on their overall emotional evaluation of an entity, such as nuclear power, when assessing its risk and benefits. In experimental investigations four separate effects have been shown, as displayed in Figure 16.

Specifically, it has been demonstrated that the provision of information that enhances the favorability of nuclear power, either by emphasizing its high benefits (scenario A), or low risks (scenario B), induces positive affect and results in a reduction of perceived risk (A) or an augmentation of perceived benefits (B). Conversely, information accentuating low benefits (C) or high risks (D) led to a diminution of favorability and negative affect, an escalation of perceived risk (C), and a reduction of perceived benefit (D) (Finucane et al., 2000).

Accordingly, the affect model suggested that risk and benefit judgments for a hazard are congruent with the overall affective evaluation of the hazard (Finucane et al., 2000). Finucane et al. (2000) contended that this phenomenon stands in contrast to a purely cognitive approach, which posits that individuals process information separately and should not automatically adjust their perception of one attribute (e.g., benefit) when presented with information about another (e.g., risk). In the context of emerging technologies, a study by C. Lee et al. (2005) provided evidence that emotional heuristics moderated the effect that knowledge about nanotechnology had on individuals' overall attitudes toward nanotechnology. For individuals with strong emotional reactions to the issue, knowledge had a weaker effect on attitudes (risk perception and support).

Figure 16. The affect model of risk



Own illustration based on Finucane et al. (2000)

Information seeking and processing

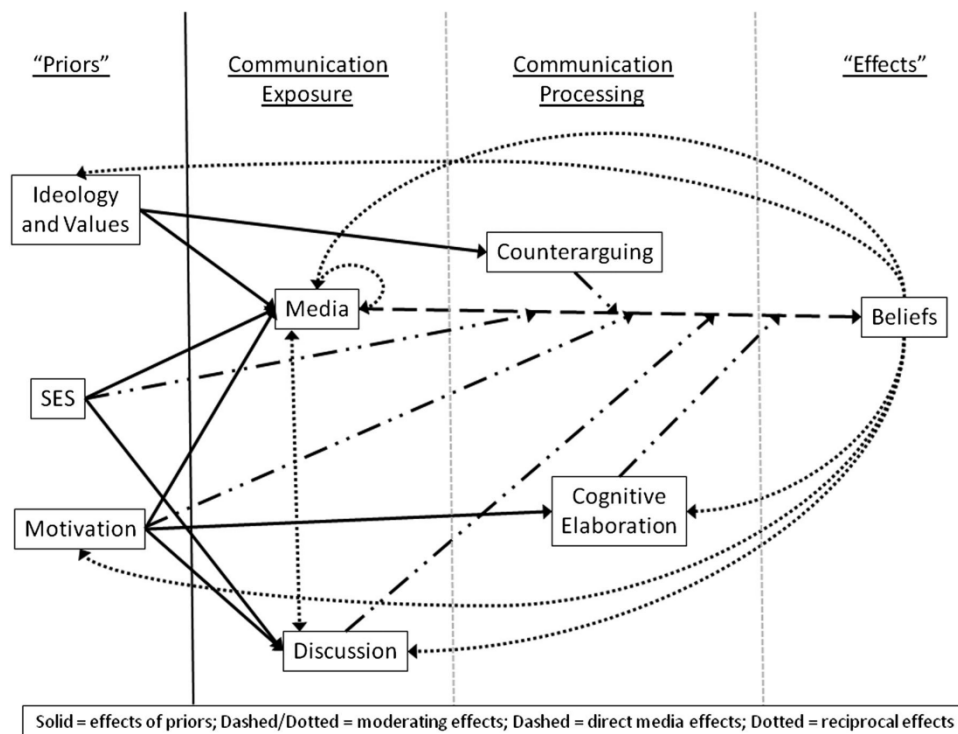
To model respondents' information processing of communication, the health risk domain provided frameworks such as the risk information seeking and processing model developed by Griffin et al. (1999). Based on these assumptions, several determinants of attitude formation were proposed, including individual characteristics, perceived hazard characteristics, affective reactions, pressure to possess relevant information, personal learning ability, and beliefs about the usefulness of information (Griffin et al., 1999). In accordance with the HSM and the theory of planned behavior, it was hypothesized that individuals who engage in more effortful information seeking and processing are more likely to develop risk-related attitudes and behaviors, which should also be more stable over time (Kahlor et al., 2003; Trumbo, 1999). However, it could be argued that the proposed framework is most relevant in the context of risk communication, in relation to specific hazard characteristics and outcomes such as preventive behavior (Griffin et al., 1999).

Within the realm of media, such as science news, the Integrated Model of Communication Influence on Beliefs (IMCIB), developed by Eveland and Cooper (2013), is particularly suitable, as it made an effort to integrate several media effects models for cognitive media effects. The IMCIB posits that individuals engage in cognitive processing of media information, thereby proposing direct effects, mediation, and moderation processes. As shown in the first component of the model refers to stable factors which were expected to have an indirect influence on beliefs through communication exposure, processing and elaboration. These “priors” were summed up as stable demographic variables (SES), less longstanding variables such as ideology and values, and moreover motivational factors, such as interest in a topic, topic relevance, and the desire to make an accurate decision. In line with other frameworks discussed in this chapter (see for example D. A. Scheufele & Lewenstein, 2005), it was expected that people who are interested in science and have a higher level of education would be more likely to read about and discuss scientific topics and would invest more mental effort in cognitively elaborating scientific messages and counter argumenting messages that are inconsistent with their beliefs than those who lack these motivations (Eveland & Cooper, 2013). The direct media effects under scrutiny were deemed possible under the precondition that media content's inherent nature is distinctly delineated, such as in news coverage centered on a salient topic, for instance, climate change, in order to elicit the anticipated effects on individuals' belief systems (Eveland & Cooper, 2013).

However, the majority of the effects of media exposure were expected to be mediated through the processing of communication messages, which can be unintentional (Eveland & Cooper, 2013). Consequently, exposure to a particular source of communication, such as television news, has the potential to influence subsequent exposure to additional news sources, including online news, or to interpersonal discussion. As proposed in moderation processes (see Figure 17), the IMCIB included the different influence of communication among subgroups, such as individuals with higher levels of motivation or prior attitudes (Eveland & Cooper, 2013). The format of the message, such as news or entertainment, could also be expected to moderate the level of counterarguing. Furthermore, the presence of counterarguing regarding a message can potentially diminish the strength of one's convictions (Eveland & Cooper, 2013). Concerning communication forms, moderation effects were expected to be amplified in the presence of complementary media sources, offering verbal and visual content or facilitating personal discussion. However, the influence of communication could also be diminished in case of redundant

media source information (Eveland & Cooper, 2013). The fundamental premise of Eveland and Cooper's (2013) model underscores the reciprocal nature of the variable relationships, emphasizing that stored relevant beliefs in communication can exert influence on the interpretation and processing of subsequent messages. From this finding, it was assumed that prior knowledge and beliefs were not specified in this regard because these concepts are included in reverse causal pathways between media use, interpersonal communication, elaboration, and motivation. Although a panel design ideally would be used to test the model, this was not the case in the present study (Eveland & Cooper, 2013).

Figure 17. Integrated Model of Communication Influence on Beliefs (IMCIB)



Source: Eveland and Cooper (2013), p.14091

4.2.2 Media Framing Effects

Studies of framing effects have primarily focused on the direct impact of a particular frame on an individual's cognitive or behavioral responses (Entman, 1993; Kühberger, 1998). Framing effects research has thus emphasized the influence of different types of frames, such as issue-specific framing, emphasis framing, or valence framing (see chapter 3.2.2). As O'Keefe (2023) has discussed, message effects studies employ two primary experimental designs. The first design involves comparing two advocacy messages to determine which is more persuasive, for example, by comparing gain and loss framing

messages. This research design emphasizes the assessment of relative message effectiveness, where the contrast between the two messages is important. The second design involves comparing an advocacy message to a control condition to assess its overall impact, which addresses the question of whether a message has persuasive power. These approaches are often used in combination within studies, enriching the research context by addressing different counter-factual scenarios (O’Keefe, 2023).

However, framing effects on attitude formation or behavioral outcomes are generally considered to be small in effect size and of questionable durability, and the exclusive focus on main effects may lead to an oversimplification of the complex interplay between framing and its influence on individuals (Amsalem & Zoizner, 2020; Lecheler & De Vreese, 2011; Mcleod et al., 2022). Thus, it has been outlined in the literature that the efficacy of a persuasive message depends on its contextual delivery, such as the specific issue being studied, as this may influence the reception of the message and its alignment or conflict with the audience's prevailing attitudes (Lecheler et al., 2009).

Based on the science communication literature, developing an in-depth understanding of scientific facts and knowledge of emerging technologies would require substantial effort on the part of the public and may consequently not be pursued (C. Lee et al., 2005; D. A. Scheufele & Lewenstein, 2005). For such issues, where the audience has relatively little knowledge and pre-existing attitudes, framing effects are expected to be stronger (McLeod & Detenber, 1999). Previous research has shown that framing effects are also moderated by additional factors, meaning that their influence depends on audience characteristics, message characteristics, and broader contextual elements (Chong & Druckman, 2007). In particular, individual-level moderators have the capacity to amplify, diminish, or even reverse the effects of framing, highlighting the need for a more nuanced examination of framing mechanisms (Lecheler & De Vreese, 2019). The table in the Appendix provides a comprehensive overview of 34 studies included in the following literature review, which focuses on studies of message effects. A variety of theoretical approaches have been used as the basis for the studies, including framing theory, prospect theory, and dual-process models. Rather than providing a comprehensive overview in the context of the aforementioned theoretical frameworks, this chapter focuses on the substantial findings regarding the relationship between different types of message framing variables on outcome variables related to attitude formation toward emerging technologies, as well as moderating and mediating individual factors.

Issue-oriented framing

Experimental studies have examined whether the generic framing of emerging technologies regarding their economic potential, policy background, or societal impact influences respondents' attitudes on the issue (see for example Cobb, 2005; Schütz & Wiedemann, 2008). In this regard, research has demonstrated that social context framing (see for example Chong & Druckman, 2007) in which a technology is embedded has been shown to influence risk perception. For instance, evident in the effect of characterizing the source of information as small or medium-sized compared to large enterprises, which were described as benefiting from nanotechnology, was shown to lead to lower risk perception (Schütz & Wiedemann, 2008). Using definitions of nanotechnology, Anderson et al. (2013) researched the influence of framing as applications, monitoring devices, drug-related items, or risks and benefits. While support for nanotechnology was higher in the application condition, highlighting the risks and benefits stimulated interest in more information about nanotechnology.

The impact of vehicle labeling on perceptions of self-driving vehicles was the focus of a study by Liu et al. (2021). In this study, participants reported higher levels of trust and perceived benefits when vehicles were labeled as intelligent, automated, or autonomous, as opposed to driverless. These labels also evoked higher positive affect and marginally lower negative affect, with naming indirectly influencing behavioral intentions through trust, perceived benefits, and positive affect. In addition, L5 vehicles, which are capable of driving themselves in any circumstance that a human driver could, were associated with a higher perceived benefit compared to the descriptions of fully automated or autonomous vehicles. This association was particularly pronounced when the term "driverless" was used. Through the mechanisms of trust and positive affect, this naming also influenced behavioral intentions indirectly (Liu et al., 2021).

In relation to the subject of stem cell research, newspaper articles that incorporated political conflict in opposition to a scientific framing led participants to perceive adult stem cell research as more ethical and credible than embryonic stem cell research (Stewart et al., 2008). Moreover, the positive association with benefits was found to produce more favorable attitudes toward stem cell research. This phenomenon can be attributed to the activation of issue-related schemas in response to the framing of the news (F. Shen, 2004). According to Gustafson and Rice (2019), the application of uncertainty framing has been demonstrated to result in lower claim belief and credibility for climate change in comparison to framing of scientific or technical uncertainty. However, no differences were

identified between uncertainty conditions in respondents' perceptions with regard to GMO food labeling. A study by Kreps (2014) examined the impact of framing in political debates on unmanned aerial vehicles (UAVs), more commonly referred to as "drones". The study investigated whether the framing of drone strikes as being in accordance with international humanitarian law (IHL) or having legal authorization influenced support for the drone policy. It has been shown that the presence of contested assumptions regarding IHL was associated with a decline in support, while arguments pertaining to legal authorization exhibited a lesser degree of influence (see Kreps, 2014).

By conducting an extensive experimental study of issue-oriented framing and message sidedness, Cobb (2005) demonstrated the presence of consistent, yet small framing effects. Specifically, the study revealed that risk and benefit frames exerted a more significant influence on the perception of risk and benefit associated with nanotechnology in comparison to frames based on general scientific beliefs, such as the cornucopian perspective. Furthermore, the present study revealed that risk frames showed a more substantial influence in comparison to benefit frames, while one-sided frames demonstrated a greater impact than two-sided frames (Cobb, 2005). Concerning the issue of emphasis framing, empirical evidence suggests that information is more likely to be endorsed when it is presented in a manner that is ideologically congruent with the ideological orientation of the recipients. This phenomenon is particularly pronounced when the information is presented to align with the ideological stance of the recipients. For instance, when individuals are presented with an article that is congruent with their own political ideology⁴⁸, the information may evoke indirect effects on their behavioral intentions via their attitudes (Luong et al., 2019).

Argument-based effects

Drawing from dual-process models (see chapter 3.2.1), the variable of *argument quality* plays an essential role in attitude formation when strong message arguments result in attitude change. This occurs through the central route of message processing when the individual has a high ability and/or motivation to process the message (Petty & Cacioppo, 1986a, 1986b). In their (2019) study, Manca et al. sought to demonstrate the moderating influence of issue involvement on attitude formation regarding sustainable transport. To this end, they manipulated argument quality, source expertise, and anticipated emotions.

⁴⁸ For liberals this was the case for reading pro-renewable energy articles and for conservatives reading anti-renewable energy articles (see Luong et al., 2019).

In accordance with the theoretical framework of the ELM (see, for example, Petty et al., 1983), it was found that higher levels of personal involvement were associated with higher levels of implicit attitude on the issue of sustainable transport when the argument was strong and lower levels of implicit attitude when the argument was weak.

Comparable outcomes were documented in the study by Frewer et al. (1999), which focused on attitudes toward genetically modified (GM) animals in food and agriculture. In instances where individuals perceived the relevance of the issue to be high, compared to low issue involvement, the persuasiveness of the arguments had a more essential effect on the rejection of the use of GM animals. Moreover, a link was established between elevated levels of cognitive engagement, as gauged by a thought-listing procedure, and more profound reflections concerning the technology, thereby indicating that more extensive processing exerts a significant impact on attitudinal outcomes.

In the context of several emerging technologies, Knobloch-Westerwick, Johnson, et al. (2015) examined the effect of supporting or opposing and exemplar or numeric arguments for the issues of fracking, genetically modified foods, biofuels and nanotechnology on issue support. The authors identified evidence indicative of confirmation bias in this context, as numerical messages that aligned with pre-existing attitudes exhibited the most significant impact on attitudes. For the issues of fracking and nanotechnology, numerical and exemplar-based messages were found to be effective in shaping attitudes. In contrast, for biofuels, only exemplar-based messages had a significant impact. Furthermore, participants who showed higher levels of empathy allocated more time to exemplar-based messages, while those with superior numeracy skills demonstrated a reduced engagement with these messages. Nonetheless, the subject in question, when considered as a within-group factor, had no effect on the observed patterns related to message exposure (Knobloch-Westerwick, Johnson, et al., 2015).

Additional studies have evidenced the role of prior attitude towards the issue as a relevant moderator in terms of attitude formation. In accordance with this matching principle, perceived message effectiveness is determined by the degree to which the message corresponds to the attitude. Messages that align with an attitude are perceived as more favorable. For instance, individuals who hold scientific views that are consistent with the notion of a link between autism and vaccines, based on weight of evidence, are more likely to develop accurate beliefs (Dixon et al., 2015). Evidence for biased processing of technology information was found by Druckman and Bolsen (2011), who observed that individuals who initially opposed a technology, such as nanotechnology, rated negative

information as more convincing, thereby reinforcing their original stance. Notwithstanding the aforementioned effects, the study found no evidence of attitude polarization, meaning that exposure to framed or factual messages did not lead to more extreme opinions over time.

Other investigations draw on the combined influence of message and source characteristics (Frewer et al., 1997; Manca et al., 2019). Scientific experts are generally regarded as more credible sources of information due to their specialized knowledge, training, and perceived independence. In contrast to other sources of information, such as government agencies, which may be perceived as influenced by political or regulatory agendas, medical professionals are expected to rely on scientific evidence and clinical experience, thereby enhancing the credibility of their assessments (Manca et al., 2019; Weingart, 2023). In the context of source effects, empirical evidence has demonstrated that scientific information is often perceived as less factual when it is disseminated by governmental entities compared to when it was presented by highly credible medical sources (Frewer et al., 1997).

According to the extant literature, transportation or immersion of narrative and design elements in interaction with message style has been demonstrated to influence the perceived temporal distance to products and thereby enhance persuasion (Meyers-Levy & Maheswaran, 1992). In the context of technological products such as robotic vacuums and electric cars, Karpinska-Krakowiak et al. (2023) observed various matching effects between temporal distance and argument type. Specifically, when temporal distance was low (i.e., an event in the near future), abstract arguments elicited more favorable responses regarding the issue. Conversely, high temporal distance (i.e., an event in the distant future) rendered concrete arguments more effective. However, the temporal distance of the argument, when combined with concrete arguments, led to heightened purchase intentions in comparison to abstract ones. Conversely, when the temporal distance was elevated, abstract arguments elicited more favorable purchase intentions than concrete ones (see Karpinska-Krakowiak et al., 2023).

Equivalence framing

As discussed in Chapter 3.2.2, equivalence framing also known as valence framing (see for example Druckman, 2001a), is a framing type category that has been evaluated in the context of how different, but logically equivalent phrases influence individual preferences (Tversky & Kahneman, 1987). While emphasizing the distinction between positive and

negative consequences, as exemplified by goal framing techniques, individuals' perceptions are expected to be influenced (Levin et al., 1998). As one type of valence framing, the persuasive potential of gain or loss framing messages has been extensively investigated in meta-analyses (see for example O'Keefe & Jensen, 2006; O'Keefe & Jensen, 2007). The relative influence of gain and loss framing can be argued to be dependent on the issue context. This is exemplified in the domain of health communication, as effects of "fear appeals" demonstrate aversive consequences that are positively related to attitude, behavioral intentions, and behavioral outcomes, for example, towards cigarette smoking (R. W. Rogers, 1983; Tannenbaum et al., 2015). Research has demonstrated that the impact of fear appeals is moderated by efficacy statements and targeted messages (Tannenbaum et al., 2015), as well as mediated by respondents' fear (R. W. Rogers, 1983).

It is evident from an evaluation of existing empirical literature that only a limited number of studies have explicitly investigated the impact of gain and loss framing of emerging technologies. Rather, these studies have focused on other operationalizations of valence framing. A study by Thacker et al. (2020) revealed that subjects exposed to a message highlighting the benefits of genetically modified foods (GMFs) or both benefits and risks exhibited a substantially more favorable disposition towards GMFs compared to subjects exposed to a message underscoring the drawbacks of GMFs. Moreover, the presence of positive information and prior attitudes that were favorable resulted in a reduction in misconceptions regarding the issue. In the context of online communication, Anderson et al. (2014) conducted an experimental study to investigate how the tone of user comments and their valence influence perceptions of the risks and benefits of nanotechnology. Furthermore, a blog post with a neutral tone was used as a stimulus. Consequently, the presence of uncivil user comments resulted in an elevated perception of risk associated with nanotechnology among study participants, particularly among individuals with strong religious beliefs. Moreover, Palm et al. (2025) reported that positive messages about AI increased belief in positive future impacts, perceived benefits of the technology, and support for technology development in this area, while negative messages increased participants fear, perceived risks, and decreased their support and trust in science.

Regarding health compliance behavior, O'Keefe and colleagues (2007) found that loss-framed appeals emphasizing the disadvantages of noncompliance with the communicator's recommendation on disease prevention behaviors were more persuasive than gain-framed messages which emphasized the advantages of compliance. Experimental studies concerning the communication of information regarding the coronavirus (Covid-

19) pandemic revealed that loss-framed messages are perceived as more effective in conveying risks, while gain-framed messages, especially those with focus on health interventions are more effective in motivating individuals to engage in behaviors that prevent the spread of the virus and, moreover, are perceived as stronger messages (Gantiva et al., 2021). Nevertheless, in a study encompassing 15,929 participants from 84 nations, Dorison et al. (2022) found that compared to gain framing, loss framing produced heightened anxiety levels among participants on a cross-national scale. However, their findings underscored the negligible influence of both message framing types on information seeking, attitudes, and behavioral intentions.

Furthermore, Reinhart et al. (2007) provided evidence that gain-framed messages on organ donation evoked more positive message reactions and greater behavioral intentions compared to loss-framed messages. Psychological reactance acted as a mediator in the relationship between framing and message reactions, with gain-framed messages producing lower levels of psychological reactance and manipulative intent and more positive message reactions than loss-framed messages. In contrast, the utilization of loss frames has been demonstrated to elevate perceptions of manipulative intent and increased reactance in comparison to gain-framed messages. A study by Lu (2016) indicated that the combination of message valence and emotional appeals is effective in promoting information seeking and behavioral intention of environmental policy support when framed as a sadness appeal and gain. The other experimental factor levels of hope appeal had a greater impact in this regard when combined with loss framing.

Visual presentation and message congruency effects

Arguments in messages have been shown to be more effective when they align with the underlying basis of an attitude (Petty & Wegener, 1998b). In the case of arguments in matched messages, recipients are more likely to hold favorable opinions under conditions of high elaboration likelihood (Chaiken & Maheswaran, 1994; Lavine & Snyder, 1996). Moreover, effects are expected to occur for message cues such as the visual presentation of an issue under low elaboration likelihood (Chaiken, 1987). It has been documented in the existing literature on memory activation processes and message elaboration that visuals have a significant impact on persuasive efficacy, as framed by media (Coleman, 2010; Powell et al., 2015; Seo & Dillard, 2019). In a series of experimental studies across different populations, Tal and Wansink (2016) found that *visual and scientific cues* enhanced perceived medication effectiveness. Simply including graphs that mirrored the

textual information about the development of illness incidence led to higher effectiveness ratings of the drug than text alone, especially among individuals who believed in science more strongly. Additionally, the inclusion of a fictitious chemical formula in the presentation of the drug resulted in a perception among a sample of the general population that the drug was more effective and longer-lasting than a text-only condition. The impact of the framing of stem cell research in photographs was examined by Dahmen (2012) by providing a political, medical, scientific, or ethical visual context. While the experimental conditions did not result in a change in attitude regarding the issue, the results of the eye-tracking data demonstrated an effect on visual attention to the stimuli. Furthermore, Hart and Feldman (2016) found that solar panel imagery in news stories increased perceptions of efficacy. Participants exposed to action-focused text felt more empowered to act, and Democrats reported higher efficacy perceptions overall.

As evidenced by Bingaman et al. (2021), the framing of AI in a text condition yielded higher support for the development of AI when compared to the "Pandora's box" frame, which highlighted potential hazards. The present study also provided evidence for a message congruency effect, whereby the tone of the text aligns with an accompanying image. Therefore, the level of support for artificial intelligence (AI) was at its highest when the social progress frame was paired with benign images of virtual assistants. By contrast, the level of support for AI was at its lowest when the Pandora's box frame was combined with menacing images from popular films (see Bingaman et al., 2021). By manipulating image and text frames related to the conflict in the Central African Republic, Powell et al. (2015) found that obligation-framed images alone increased support and behavioral intentions more than risk-framed ones. However, text framing influenced support for intervention only among those respondents with high issue-specific knowledge. When both frames were presented simultaneously, the text framing influenced attitudes toward the military intervention, while the image framing primarily affected behavioral intentions such as donating. Furthermore, emotional responses exerted a more substantial mediating effect on the impact of images than text, both in isolation and in conjunction with both modalities (see Powell et al., 2015).

Additionally, environmental messages that incorporated visual components, such as infographics, proved to be more engaging than text-only messages (G. Huang et al., 2019; Lazard & Atkinson, 2014). As Lazard and Atkinson (2014) demonstrated for recycling and GMOs, infographics led to greater elaboration than text- or visual-based messages. This effect held across different learning preferences and visual literacy levels.

Even low-visual-literacy or verbal learners showed higher elaboration when exposed to infographics. The effect of gain and loss framing, different message modality, and the *reference point of the message* was researched by G. Huang et al. (2019) in relation to the issue of recycling. A three-way interaction revealed that loss-framed messages referencing others were more effective, particularly when presented as infographics, in increasing perceived harm to oneself and others as a reference point compared to text-based messages.

A notable body of research has focused on the alignment between text and visual messages, particularly in the context of persuasive communication. This alignment, or "*message matching*," has been theorized to enhance persuasive impact, while misalignment is believed to have the opposite effect (Seo & Dillard, 2019). For instance, in the context of fear appeals, the presentation of loss-framed messages and unpleasant images has been demonstrated to generate an amplification effect (Zhao et al., 2014). The impact of gain and loss framing and matched images was further examined in research conducted by Seo et al. (2019; 2013). By employing a mixed factorial design, one of their studies revealed that a loss-framed message combined with a neutral image led to an unfavorable dominant cognitive response, potentially an effect induced by triggering reactance in respondents (Seo et al., 2013). Furthermore, the presence of an image in loss-framed messages about sunscreen was found to significantly increase fear levels (Seo et al., 2013).

Another study by Seo and Dillard (2019) investigated how framing, image matching, and message topic influenced persuasion by hypothesizing that the utilization of matching images with message framing would result in more favorable perceptions of the message, which would subsequently influence emotions, cognitions, and behavioral intentions. According to the study's findings, the hypotheses were found to have only partial support. In gain-framed messages, the presence of matched images to the text led to more favorable valence judgments, particularly for a message on travel, while the effect was less evident for a tablet product related message. Messages presented in a loss-framed manner yielded varied outcomes, with certain effects aligning with the anticipated outcome that matched images eliciting less favorable assessments. Furthermore, the manner in which messages are framed has been demonstrated to exert a significant influence on the perceived valence of the message, with gain-framed messages receiving higher ratings in comparison to loss-framed messages. Structural equation modeling further revealed that perceived message valence functioned as a mediator in the effects of framing and image on emotional and cognitive responses. Positive emotions, such as happiness and

contentment, in conjunction with a favorable dominant cognitive response, have been shown to positively predict behavioral intentions. Conversely, negative emotions, including anger and discontent, have been demonstrated to negatively influence persuasion (see Seo & Dillard, 2019).

In the context of green advertising, J. Lee and Cho (2022) found that gain-framed text had a stronger effect on attitude and purchase intentions than loss-framed text and positive images compared to negative images. However, message congruency analysis also revealed that congruent combinations of gain-framing with positive images yielded more favorable outcomes than incongruent pairings of gain-framing with negative images. Conversely, in the loss-framing condition, incongruent pairing with a positive image proved to be more persuasive than with a negative picture. This phenomenon was further compounded by the heightened negative reactions to incongruent gain-framed advertisements exhibited by consumers with low issue involvement. In such instances, the valence of the image impacted their responses to incongruent advertising, leading to more pronounced negative reactions and attitudes toward a gain-framed message accompanied by a negative image. Moreover, this tendency was more pronounced among consumers with low issue involvement compared to those with high issue involvement (J. Lee & Cho, 2022).

In conclusion, communication studies focused on the visual representation of science in public communication outside of the scientific community, which is primarily aimed at a lay audience. These studies also examined the effects of such images, including experimental research on how they influence understanding, attitudes, and behavior. While images related to certain scientific topics, such as climate change, have been well researched in this context, studies of the issue of emerging technologies remain scarce (see also Metcalfe, 2018).

4.2.3 Influence of the Source

A seminal factor in heuristic-based attitude formation is source credibility. Research has demonstrated that individuals are more inclined to accept information and develop positive attitudes when it is presented by a source they perceive as credible or trustworthy (Chaiken & Maheswaran, 1994; Hovland et al., 1953; Hovland et al., 1949; Hovland & Weiss, 1951). Source credibility functions as a heuristic cue that facilitates decision-making, given that individuals often lack the resources or motivation to critically evaluate the content of a message (Chaiken & Maheswaran, 1994). Instead, they rely on heuristics

such as the perceived expertise, trustworthiness, or the likeability of the source to guide their attitudes (Puckett et al., 1983). For instance, when scientists or experts endorse a particular technology or public health measure, people are more likely to form positive attitudes toward it, even if they do not fully understand the underlying science. Conversely, if the source is perceived as biased or lacking expertise, individuals are more likely to reject the message, regardless of its factual accuracy (J. D. Jensen, 2008; Renn & Levinde, 1991). It has also been evidenced that recipients rely on the credibility of the source to a greater extent when they possessed no prior attitudes or knowledge about the issue (Kumkale et al., 2010).

In order to explore various angles and contexts in the research on credibility evaluations, the following literature review will focus on the credibility assessments of scientists, journalists, and expert sources, particularly in the context of scientific communication and news reporting. However, in the evaluation of expert sources, prior research has primarily emphasized credibility cues such as expertise and competence (Pornpitakpan, 2004). Comparatively less attention has been devoted to the role of sociodemographic factors, such as gender, age, or race in shaping perceptions of credibility (Pearson, 1982). Nevertheless, the personalization of experts, such as through the use of photographs accompanying interview statements or university website profiles, may act as heuristic cues that influence perceived expertise and trustworthiness (Gheorghiu et al., 2017; Hubner & Bullock, 2024). This literature review will therefore also address the potential impact of these visual and demographic cues. The empirical studies examined in this analysis are grounded in source credibility theory. These studies aimed to explore how various independent variables, such as expertise, visual representation, and sociodemographic traits, affect dependent variables. As such, the dependent variables of this overview include source credibility perceptions and broader evaluations of the message or messenger.

Trust and credibility perception of scientific sources

A compelling body of research has underscored the necessity of incorporating values, trust, and social context into the discourse of science communication (Bauer et al., 2007; Siegrist, 2019). High levels of trust in scientific experts have been demonstrated to foster more favorable attitudes toward scientific advancements (Cacciatore, Browning, et al., 2016). Conversely, a dearth of scientific literacy has been demonstrated to engender skepticism and unfavorable attitudes (Weingart, 2023).

Nonetheless, the evaluation of scientists' expertise has been shown to be contingent on the subject of investigation (Greve-Poulsen et al., 2021). A number of studies have examined the impact of scientific information and source characteristics in the thematic context of genetically modified foods (GMOs). In their study, Andrews et al. (2025) investigated the influence of topic (GMOs or climate change), message order, and stance alignment on perceptions of source credibility, particularly in terms of expertise and trustworthiness. These findings indicated that both scientists and YouTubers were perceived as more credible when their message aligned with participants' pre-existing attitudes. However, the influence of message congruency exhibited variation according to source type. For scientists, the credibility of their research was found to be particularly affected when their stance was revealed before their identity, suggesting that perceived expertise is filtered through prior attitude congruency. Conversely, when the source was a content creator on YouTube, participants demonstrated a more pronounced ability to differentiate between congruent, incongruent, and ambivalent messages. In general, the credibility of the source was most pronounced when the communicator's message aligned with the audience's existing perspectives, irrespective of their professional background (Andrews et al., 2025).

An inquiry into the impact of Twitter-based corrections on public misperceptions regarding the safety of GMOs was conducted by Bode et al. (2020). Utilizing a pre-post-test design, the researchers examined the extent to which a corrective reply from the Pew Research Center to a meme propagating misinformation influenced participants' beliefs and behaviors. It was found that the correction led to a substantial increase in perceptions of scientific consensus on GMO safety in comparison with exposure to misinformation alone. Among individuals who initially exhibited moderate to high levels of misperception, the correction indirectly reduced those misbeliefs and led to a lower likelihood of avoiding GMOs. However, the present study found that incorporating popularity cues, such as "likes", into the corrective response did not enhance its effectiveness in terms of improving perceptions of scientific consensus, reducing misperceptions, or increasing perceived credibility of the source. In regard to online comments, Y. Kim (2015) conducted a study on the credibility of sources, perceptions of food irradiation, and biofuels. The study revealed that the presence of comments expressing support did not exert an influence on the perception of public acceptance of the news article's position. However, the analysis did demonstrate that comments that were in opposition decreased, while those that expressed support increased, when compared with the absence of comments.

Overall, the participants' evaluation of the news was influenced by their perception of how others would accept it, thereby demonstrating that comment sentiment shapes news credibility through social comparison mechanisms.

Research has delved into the influence of expectancy violations, such as unexpected combinations of communicator style and expertise, on the reception of technology-related messages by the audience. For instance, Yuan et al. (2019) discovered that source expertise exerted a more pronounced positive influence on perceived message quality when a scientist employed an assertive communication style, as opposed to a polite style. Furthermore, preexisting attitudes toward the issue of genetically modified organisms (GMOs) more strongly influenced perceptions of writer likeability under aggressive communication conditions. In contrast, when the communicator adopted a polite style, the positive impact of expertise on expectancy violation was stronger than under aggressive conditions. Conversely, L. König and Jucks (2019) reported a consistent negative association between the use of aggressive language and reduced message credibility, subjective comprehension, and perceptions of expertise, integrity, benevolence, and likability. The heightened perceptions of machiavellianism observed in the study were attributed to the aggressive communication exhibited by the subjects. In addition, lobbyists were perceived more negatively than scientists, receiving higher ratings on machiavellianism and lower evaluations on traits such as integrity, benevolence, and likability.

By manipulating the funding source of research and the citation style, Sprecker (2002) found no direct effects. Nevertheless, subjects who expressed a high degree of engagement with environmental issues perceived scientists as more trustworthy than those who indicated a moderate or low level of engagement. This finding stood in contrast to the prevailing expectation of a significant impact of source cues under conditions of reduced elaboration capacity. Across five scientific domains, Treise et al. (2003) discovered that content from .gov domains and NASA received consistently higher ratings in terms of expertise, likeability, and objectivity when compared to content from domains that end with .com. Furthermore, participants exhibiting a high degree of involvement demonstrated a tendency to evaluate articles more favorably. Conversely, those with a low degree of involvement were more likely to perceive sources as objective, irrespective of the subject matter. Additionally, scientists were considered to be more authentic sources of information, and therefore more expert, in comparison to social media influencers (Zhang & Lu, 2023). This phenomenon led to an increase in parasocial interaction and information-seeking intentions. As indicated by Zhang and Lu (2023), the application

of professional self-disclosure (PFSD) was found to be associated with a greater level of credibility in comparison to the use of personal self-disclosure (PSD).

Sociodemographics influencing credibility perception

In essence, stereotypical depictions of scientists in the media have the potential to influence perceptions of expert roles, thereby affecting credibility perceptions and potentially impacting young people's career choices (Chambers, 1983; Steinke, 1997). The field of media expertise is still male-dominated, as evidenced by the underrepresentation of female experts in news media (Niemi & Pitkänen, 2017). This phenomenon mirrors the underrepresentation of female academic authors in male-dominated disciplines (J. Huang et al., 2020). Gender imbalances in expert utilization in news coverage can be attributed to the Matthew effect, which posits that journalists often contact researchers with whom they have previously collaborated and are personally aligned (Albaek et al., 2003; Niemi & Pitkänen, 2017). Empirical evidence has demonstrated a persistent underrepresentation of women in science magazines (Loverock & Hart, 2018) and stock photographs, particularly within the AI sector (Cave et al., 2023). Furthermore, female scientists are often attributed masculine characteristics, resulting in different expected consequences for their evaluation by audiences. This may include backlash effects of violating stereotypical perceptions of incompatibility for the scientific field or emphasizing their biographies as exceptional and serving as role models (LaFollette, 1988; Steinke, 2005). The impact of expert gender on perceived credibility has been the subject of extensive research, predominantly within the context of news media reporting.

As indicated in the research by Bigham et al. (2019), the communication of information regarding CRISPR technology was found to be more credible when originating from female sources in comparison to male sources. Additionally, Ozer (2023) investigated the influence of author gender, expertise, and political alignment on perceptions of credibility and article selection in political media. In this study, sources with a high level of expertise were regarded as more credible, while those with a low level of expertise were viewed less favorably. In the absence of expert cues, male authors were perceived as more credible and selected more often than female authors. However, the incorporation of expertise cues led to an enhancement in the selection of female authors, thereby helping to counteract any existing gender bias. Furthermore, participants exhibited a marked preference for articles authored by individuals who aligned with their own political party over those authored by individuals representing opposing political parties. The findings

indicated that cues with a high degree of expertise increased the probability of selecting both in-party and out-party sources. This effect remained consistent irrespective of the author's gender (Ozer, 2023).

Using a variety of sub-studies and samples, Paul et al. (2022) found minimal evidence that the gender of the reporter, the source, or the gendered nature of the issue influenced perceptions of credibility for reporters or news outlets. However, stories covering feminine issues were generally associated with higher credibility among reporters and news outlets compared to masculine issues. When stories addressed masculine or neutral topics, audiences perceived the credibility of reporters and news outlets as higher than when stories addressed feminine topics. Furthermore, stories addressing feminine issues and authored by female journalists were considered more relatable, particularly by female readers. However, female readers also exhibited a tendency to regard news outlets covering feminine issues as less credible in comparison to male readers' assessments of news coverage pertaining to masculine issues. In an examination of various online news sources ascribed to authors, Haim and Maurus (2021) found that a computer-generated author was perceived as less credible than a human author. However, when authors addressed counter-stereotypical subjects, such as women writing about football without sexist remarks, their credibility was found to be at its minimal. Conversely, sexist comments led to an unexpected increase in the credibility of both the source and the message for female journalists writing on masculine themes, suggesting a reactance effect.

With regard to the expectations of scientists in terms of stereotypical research area classifications, a study by Knobloch-Westerwick et al. (2013) found that scientific abstracts authored by male authors were given higher ratings in terms of scientific quality, particularly for research on topics that are traditionally dominated by males, such as physics or engineering. Conversely, female authors received lower ratings for work of a similar nature, particularly in the presentation of research in these male-dominated fields. It is noteworthy that subjects pertaining to males received considerably higher ratings, suggesting a bias in favor of gender-topic congruency. This phenomenon indicates that individuals tend to hold more favorable views of research when the author's gender aligns with stereotypical expectations associated with the subject matter. With regard to the expression of interest in collaboration, female authors garnered a greater degree of interest when engaged in research related to female-oriented subjects, such as education or healthcare. However, this heightened interest was not observed in cases involving gender-

neutral subjects. In contrast, male authors garnered the most collaboration interest when working on topics related to masculinity (see Knobloch-Westernwick et al., 2013).

Evidence from existing literature on the subject shows that gender affinity effects involve participants' preference for sources of their own gender (see, for example, Dolan, 2008). For instance, this phenomenon has been demonstrated in the evaluation of newspaper columnists (H. A. White & Andsager, 1991). In their website credibility study, Flanagin and Metzger (2003) indicated that credibility ratings were moderated by participants' gender. Male participants exhibited a tendency to rate websites as more credible, irrespective of the gender of the website owner and the content of the messages on the websites, as compared to female participants. Female participants, particularly those who accessed the website authored by women, perceived the website and its content as significantly less credible than did male participants. This finding indicates that women exhibited a heightened level of critical evaluation when assessing a website attributed to another woman (Flanagin & Metzger, 2003).

Other investigations have also demonstrated an absence of evidence supporting a gender affinity effect, with participants expressing a preference for scientists of the opposite gender (Hubner & Bullock, 2024). It can also be argued that scientists of different genders might be rated differently for specific personality traits by participant gender. In the context of a comparative study, female participants were found to exhibit a higher level of agreement than male participants in terms of the evaluation of interview texts and photographs of female scientists (Armstrong & Adamson, 2021). This observation was particularly evident in the assessment of attributes associated with self-control, where female participants demonstrated a higher level of agreement compared to male participants. In contrast, male participants exhibited a higher level of agreement with regard to the attributes of being biased and dramatic, as perceived in the interview texts and photographs of female scientists. However, female participants assigned higher ratings to male scientists than the male participants did for the perception of approachability and expressiveness (Armstrong & Adamson, 2021).

A review of contemporary media portrayals reveals a striking underrepresentation of older age groups, a phenomenon that is especially pronounced among women (Edström, 2018; Jürgens et al., 2022). In an experimental investigation, Weibel et al. (2008) researched how the gender and age of television newscasters influence perceptions of message and source credibility. Overall, messages conveyed by female newscasters were perceived as more credible than those delivered by male newscasters. However,

male newscasters were perceived as more credible sources than their female counterparts. Therefore, a divergence between message and source credibility based on gender was suggested. While age did not independently affect credibility, older male newscasters were viewed as more credible than older female newscasters. In contrast, younger male and female newscasters were rated similarly in terms of credibility.

As suggested by Yeo et al. (2022), the perceived effectiveness of a speaker's credentials depends on the audience's emotional response rather than the speaker's gender or race. Among participants who reported lower levels of enjoyment (i.e., lower mirth), scientists were perceived as less effective communicators compared to comedians, irrespective of race. Nevertheless, an examination of faculty evaluations of postdoctoral applicants revealed that ratings of competence and hireability were influenced by candidate gender and race (Eaton et al., 2020). Participants from the faculties of physics and biology departments assigned male candidates a higher level of competence and hireability compared to female candidates who were equally qualified. Moreover, White and Asian candidates were perceived as more competent and suitable for hire than Black and Latinx candidates. These biases were particularly evident among physics faculty, who exhibited a strong preference for male, White, and Asian candidates. In contrast, biology faculty demonstrated racial bias in hireability, exhibiting a notable preference for Asian candidates over Black candidates (Eaton et al., 2020).

Visual presentation of the source

Multimodal messages have been investigated in the realm of journalism research, including the reception of infographics, interactivity, and animation (Bos et al., 2010; Holmqvist & Wartenberg, 2005). Despite this, it has been observed that the study of visualization in news and credibility assessment is an interface that has been largely overlooked in research (Meier, 2017; Peng et al., 2023). One exception is the work of N. Li et al. (2018), who examined how visual design features such as graph format and interactivity, as well as information about data source credibility, influence perceived data credibility in the context of the nuclear fuel cycle. According to the findings of the study, the format of graphs, specifically whether they were static or dynamic, did not appear to influence the perceived credibility of the graphs. However, it has been reported that dynamic graphs were perceived as less credible compared to static graphs. A discrepancy in the perceived credibility of the data was observed, with data attributed to the high expertise source,

MIT, being viewed as more credible than data from the low expertise source, the government agency DOE.

Consequently, Meier's (2017) findings indicated that articles attributed to the tabloid newspaper BILD were generally perceived as less credible, while those authored by the German Federal Environment Agency (UBA) received higher credibility ratings. In the course of this study, maps were regarded as more credible than standard images or infographics when evaluated across a range of visual formats. Specifically, the incorporation of visual components into BILD articles has been shown to enhance their perceived credibility, thereby suggesting that the presence of visual elements can serve as a partial compensatory mechanism for a perceived lack of credibility stemming from the source. Moreover, Isberner et al. (2013) examined how readers' experience with science texts and graphs affects their evaluation of information on two topics (biomass energy and electromagnetic radiation), using a design with graphs or tables as a within-subjects factor. They found that experienced readers judged texts with graphs as more plausible, while less experienced readers found graphs less plausible, likely due to increased cognitive load.

A limited number of studies have examined the effects of scientists' visual presentation as a source of information, albeit in contexts that differ from news reporting. For high school students, Good et al. (2010) found that female students exhibited superior comprehension ratings when exposed to chemistry materials featuring counter stereotypical pictures of only female scientists compared to stereotypical pictures of male-only scientists. Male students, in contrast, demonstrated no such distinction. However, there was a decline in overall interest in science as a subject, while students' interest in pursuing careers in science remained constant.

As demonstrated by Jarreau et al. (2019), examining Instagram posts by scientists revealed that self-portraits of female scientists resulted in elevated perceptions of trustworthiness and warmth, in comparison to posts containing solely scientific content. Therefore, the appeal of the scientists' gender effects was mediated by their attractiveness. Specifically, female scientists in selfies were perceived as more competent, and their presence led to a shift in gender stereotypes associated with science, toward a more female-associated image of science. This phenomenon was further explored by Hubner and Bullock (2024), revealing that female scientists were regarded as significantly more likable than their male counterparts, contingent on the visibility of their names and the gender of the scientists in Instagram posts. A subsequent mediation analysis revealed that heightened perceptions of competence and trust in science among female scientists were

mediated by increased likability. Surprisingly, study participants exhibited a preference for scientists of the opposite gender, a finding that contradicts the commonly assumed gender affinity effect.

Moreover, Gheorghiu et al. (2017) found that scientists' facial appearance influenced perceptions of their competence, morality, and attractiveness, which in turn affected interest in their research and judgments of research quality. The impact of initial impressions on professional perceptions was evident in the perception of competent and moral-looking scientists. Despite being perceived as less sociable or attractive, these scientists were regarded as conducting higher-quality work. Research participants indicated a preference for content that incorporated visual depictions of scientists who were either compelling or attractive, particularly within the context of videos and the biological sciences. The findings of the study demonstrated that female and older participants exhibited a heightened propensity to be influenced by physical appearance. It was observed that competence exerted the most substantial influence on interest and quality judgments of science. Another study by Eom et al. (2025) explored how race and gender stereotypes influence the perception of scientists' credibility in the context of gene-editing communication, using documentary film clips about CRISPR-Cas9. Its findings indicated that White scientists received higher ratings in terms of warmth and competence compared to their Black counterparts. Additionally, male scientists were rated higher in terms of credibility than their female counterparts. Black female scientists received the lowest ratings across both credibility dimensions, reflecting the impact of intersecting racial and gender biases.

4.3. Synthesis of Empirical Findings and Summary of Research Aims

Contextual determinants and individual-level differences

While a positive correlation exists between scientific literacy and supportive attitudes toward science and technology, this relationship is subject to variation depending on the type of technology involved (Gaskell et al., 2005; Palm et al., 2025). For more controversial technologies, such as genetically modified organisms (GMOs) or nuclear energy, increased scientific knowledge does not consistently translate into greater support (Connor & Siegrist, 2010; Verplanken, 1989). In fact, individuals may employ their knowledge to reinforce their existing attitudes through the process of motivated reasoning (Druckman & Bolsen, 2011; Kunda, 1990). An area that has received less attention is the manner in

which different categories of technologies, for example, production technologies versus consumer-facing and visible technologies, such as energy solutions, are evaluated in terms of subjective knowledge and perceived relevance. As indicated by the findings of preceding studies, technologies that are highly integrated into the context of daily life are more likely to be perceived as relevant and comprehensible by the public. In contrast, less tangible technologies may encounter a knowledge and engagement gap (Daamen et al., 1990; D. A. Scheufele & Lewenstein, 2005). The existence of spillover effects has been posited as well, such that public attitudes toward nanotechnology labeling are influenced by prevailing views on GMOs. In such cases, individuals may anchor their judgments about nanotechnology to their perceptions of the risks and benefits associated with GMOs, particularly when deferring to scientific authority (Akin et al., 2019).

Given the persistent acceleration of technological development, recent studies investigating how various technology domains are perceived comparatively, especially within the context of media communication, have been lacking. This discrepancy becomes particularly pronounced when considering the role of information behavior and media preferences. Research on science communication has frequently neglected to consider the varying impacts of media formats, including television, radio, newspapers, social media, and online platforms, on technology perception. While science news constitutes a significant information source, studies such as the Eurobarometer (European Commission, 2021c) suggest that citizens frequently engage with science through conversations with family and friends. These informal channels have the capacity to exert a powerful influence on how individuals internalize and evaluate scientific issues, especially in circumstances where formal sources are distrusted or inaccessible (Ho et al., 2011). Differences in media and information consumption patterns among population segments, such as across demographics concerning age, gender, and education have also been the subject of investigation (Nisbet et al., 2002).

Moreover, cross-national comparisons have demonstrated that cultural, educational, and media system differences significantly influence public understanding and attitudes toward science (Allum et al., 2008; J. Miller et al., 1997). The existence of a robust public service media sector, accompanied by a historical foundation of educational content, has been demonstrated to contribute to the cultivation of scientifically literate populations within a nation (Allum et al., 2008). However, a substantial proportion of extant literature continues to prioritize Anglophone countries, thereby limiting the generalizability of prevailing science communication structures to more extensive global settings

(Guenther & Joubert, 2017). In summary, there is an urgent need for updated, cross-contextual, and comparative research.

As displayed in Figure 18, the primary focus of study 1 will be on the influence of contextual variables, namely the technology type, recipients' media use, and national context, on the evaluation of emerging technologies. This encompasses the dependent variables of subjective knowledge and subjective relevance perception⁴⁹. Additionally, the role of individual differences, such as prior knowledge, issue involvement, or cognitive elaboration capacity, in moderating message congruency effects has been documented but not sufficiently integrated into broader theoretical models or practical frameworks (J. Lee & Cho, 2022; Powell et al., 2015). Notwithstanding the increasing integration of psychological and communication theories into the realm of science communication research, significant conceptual and empirical gaps persist. Conventional models that prioritize scientific literacy have demonstrated limitations in elucidating the formation of attitudes toward emerging and controversial technologies.

The available evidence suggests that individuals often rely on heuristics, such as trust in science, emotional responses, or prior attitudes, particularly when scientific information is complex, unfamiliar, or aligned with their value predispositions. Theoretical models such as the Orientation–Stimulus–Orientation–Response (O–S–O–R) (Brossard & Nisbet, 2007) and the Science Literacy and Heuristics Model (SLHM) (D. A. Scheufele & Lewenstein, 2005), which were reviewed in chapter 4.2.1, offer valuable frameworks for examining these cognitive shortcuts. However, these models have limitations in capturing the nuanced cognitive and motivational processes underlying media exposure and information engagement.

Further addressing cognitive elaboration and motivation, Eveland and Cooper's (2013) Integrated Model of Communication Influence on Beliefs (IMCIB) provides a more comprehensive approach to understanding media effects. This model incorporates both direct and mediated pathways, highlighting the importance of prior motivations, exposure patterns, and elaborative processing. It also introduced the idea of reciprocal communication influence, in which past media exposure and stored beliefs shape the

⁴⁹ Although persuasion research often refers to the concept of issue involvement, this dissertation consistently uses the term "subjective personal relevance perception" for all three empirical studies. The term subjective personal relevance perception more precisely captures an individual's self-reported appraisal of how consequential an issue is to them personally. This choice also aligns with the notion of involvement as a continuum of personal relevance (Petty & Cacioppo, 1990), in which issues become involving to the extent that they carry significant consequences for one's life (Apsler & Sears, 1968).

interpretation of future messages (Eveland & Cooper, 2013). However, the IMCIB assumes an ideal panel design to capture these reciprocal effects, which has rarely been implemented in empirical studies (Eveland & Cooper, 2013). Moreover, although the model recognizes moderating effects of message format and individual characteristics, it remains underutilized in studies focusing on controversial science issues.

As earlier research has shown, value predispositions, including moral beliefs and personal values, play a significant role in shaping public attitudes about science-related issues, such as stem cell research (Ho et al., 2008; Ho et al., 2010). However, many of the extant studies do not adequately capture audience heterogeneity, such as differences in cognitive capacity, interest, or engagement with science. Furthermore, the presence of redundancy or complementarity in media messaging has been identified as a significant factor, yet the precise mechanisms through which these effects manifest remain to be fully delineated. As demonstrated in the literature review, a total of 30 out of the 61 studies summarized in the table located in the appendix examine potential moderators of message effects.

In the context of the present dissertation, this underscores the importance of researching individual-level factors when examining how audiences perceive and evaluate scientific messages about emerging technologies. It is imperative to consider moderating variables, as disregarding them can obscure crucial effects and result in an underestimation of the influence of media messages on diverse audiences (Valkenburg & Peter, 2013). As focus of this research, the role of individual-level variables compared to contextual variables will be a particular focus for the first empirical study and is also of interest for the investigation of message framing effects (study 2) and source credibility effects (study 3).

Message framing effects

As discussed in chapter 4.2.2, message framing has been the subject of extensive research due to its impact on shaping recipients' attitudes, decision-making, and behavioral intentions across various domains (Chong & Druckman, 2007; Tversky & Kahneman, 1987). Gain and loss framing has been defined as a communication strategy whereby information is presented in terms of potential benefits (gains) or potential costs (losses), despite the underlying content remaining logically equivalent (O'Keefe & Jensen, 2006). This distinction is rooted in prospect theory (Kahneman & Tversky, 1979; Tversky & Kahneman, 1987) and highlights how individuals tend to respond differently depending on whether

outcomes are framed positively or negatively. For instance, a message might emphasize the advantages of engaging in a certain behavior (gain frame) or the disadvantages of not engaging in it (loss frame) (O’Keefe & Jensen, 2006). Research has demonstrated that these subtle shifts in wording can exert a significant influence on attitudes, emotional reactions, and behavioral intentions across a variety of domains, including health, science, and environmental communication (Chong & Druckman, 2007; O’Keefe & Jensen, 2006; Tannenbaum et al., 2015).

Despite noteworthy advancements in understanding how visual presentation and message congruency affect persuasion, several critical gaps persist in the extant literature, hindering a comprehensive grasp of these effects, particularly in the context of emerging technologies. Although the impact of congruency — the alignment between message text and visuals — on persuasive impact is well-documented (see for example J. Lee & Cho, 2022; Powell et al., 2015), the mechanisms underlying these effects remain to be fully elucidated.

Research consistently indicated that the effectiveness of an argument is contingent upon its congruency with the underlying attitude base and the recipient's elaboration likelihood. Specifically, the impact of matched textual arguments is enhanced by high elaboration, while the influence of visual cues is augmented by low elaboration (Chaiken, 1987; Petty & Wegener, 1998b). However, empirical findings indicate that these effects are not uniform; visuals have the capacity to either reinforce or undermine textual messages, contingent upon factors such as framing, emotional tone, and the nature of the visual itself (Coleman, 2010; Seo & Dillard, 2019). However, there is a lack of systematic experimental studies that have examined how the content of images interacts with message framing (gain vs. loss) to produce congruency or dissonance effects, particularly in the context of scientific or technological communication.

As demonstrated in studies such as Tal and Wansink's (2016) research on medication effectiveness and Bingaman et al.'s (2021) study on AI, congruency between images and textual frames has been shown to shape issue support levels. However, the extant literature on this subject typically examines a limited number of cases or specific technologies, leaving open the question of how generalizable these congruency effects are across diverse topics, media channels, and audience segments. The interaction between message framing, image congruency, and audience characteristics is further complicated by findings on issue involvement and cognitive elaboration. For instance, J. Lee and Cho (2022) found that consumers with low issue involvement react more negatively to

incongruent combinations of gain-framed text and negative images than those with high involvement, suggesting a critical moderating role of engagement that is often neglected. However, the precise cognitive and affective processes through which involvement modulates congruency effects — such as differential attention allocation, message processing depth, or emotional regulation — remain inadequately explored. Furthermore, existing research has focused predominantly on binary valence categories (positive vs. negative images), overlooking more complex or mixed emotional content that may better capture real-world communication scenarios (J. Lee & Cho, 2022).

In sum, to develop a more profound comprehension of the effects of visual presentation and message congruency requires an integrative, multi-method research approach that considers the interplay of message components, audience distinctions, emotional and cognitive mediators, and contextual variables. This dissertation acknowledges that framing effects on attitudes toward controversial science topics are not always observable as direct main effects. Rather, they emerge through interactions with individual characteristics such as prior attitudes, subjective knowledge, and issue involvement. These factors influence whether recipients engage in systematic or heuristic message processing and which heuristics or biases are triggered by a particular frame (Lecheler et al., 2009; J. Lee & Cho, 2022). Therefore, the inclusion of these moderating variables in study designs is essential to better understand the conditions under which visual and message framing cues affect attitude formation about emerging technologies.

As the objective of study 2 is to utilize an empirical approach to examine how message framing influences support and behavioral intentions concerning emerging technologies. The present study will examine the influence of cognitive elaboration, as defined by the Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986a, 1986b), on the utilization of visual cues as peripheral heuristics. These cues are expected to be particularly relevant in low-involvement contexts, wherein individuals demonstrate a reduced reliance on content and an increased reliance on message-related features (Chaiken, 1980). Accordingly, this study will examine the influence of message framing (gain vs. loss), the visual presentation of information, and how individual-level moderators—such as subjective knowledge, prior attitudes, and issue involvement—shape recipients' evaluations of emerging technologies (see Figure 18).

Source credibility effects

According to established cognitive models of persuasion, under conditions of low involvement, audiences frequently rely on heuristic or peripheral cues, such as source attractiveness, likeability, or perceived expertise (Chaiken, 1980; Petty & Cacioppo, 1984). This tendency is evidenced by the observation that audiences tend to place more trust in these cues than in the content of the message. However, there is a limited body of research that has empirically examined the operationalization of these cues in the context of visual characteristics of scientific sources. The nexus of visual presentation and sociodemographic factors plays a pivotal yet under-explored role in shaping public perceptions of credibility in science communication. Research in journalism and science communication has identified that multimodal elements, such as infographics, animations, and photographs, can significantly influence the perceived trustworthiness and expertise of information sources. However, despite their growing use, the study of how these visual components interact with audience characteristics to affect credibility assessments remains limited (Bos et al., 2010; Meier, 2017; Peng et al., 2023).

Another point of discussion is the integration of visual message effects with broader argumentation frameworks. While the elaboration likelihood model and related dual-process theories provide a solid foundation for understanding the effectiveness of textual arguments, their application to multimodal message congruency is constrained. For instance, the manner in which visual cues may influence the pathways of elaboration or their interaction with the quality of arguments and the credibility of sources in the formation of attitudes remains to be systematically investigated (Meier, 2017; Peng et al., 2023). This discrepancy is especially noteworthy in the context of the growing prevalence of sophisticated visual media (e.g., infographics, videos) in science communication, where the interplay or discord between visual and verbal components has the potential to significantly influence persuasive outcomes (G. Huang et al., 2019).

Recent frameworks pertaining to visual features, such as the one proposed by Peng et al. (2023), underscore the influence of visuals on credibility perceptions by drawing on the Elaboration Likelihood Model (ELM). According to this framework, visuals can affect persuasion through three distinct pathways. The first pathway is as arguments that invite systematic evaluation (e.g., data visualizations). Second, visuals can be heuristic cues based on visual quality or realism. Finally, visuals can be attention mechanisms that increase engagement through emotional or aesthetic appeal, even at the expense of deeper processing. These mechanisms are especially relevant when motivation or the ability to

process information systematically is low, highlighting the persuasive power of visual features beyond factual accuracy (Peng et al., 2023).

Furthermore, the sociodemographic characteristics of the source intersect with these visual effects to shape perceptions of credibility. The underrepresentation of female and minority scientists in media visuals mirrors broader systemic biases observed in academic and media contexts. These include the Matthew effect, which states that well-known, often male, experts are preferentially cited or featured (J. Huang et al., 2020; Niemi & Pitkänen, 2017). Such disparities in trust have been linked to gender and racial differences, with minority groups often encountering heightened skepticism stemming from societal stereotypes (Cave et al., 2023; Eom et al., 2025). Moreover, the impact of media presentations is influenced by the characteristics of the audience, including gender, age, and political orientation (Anderson et al., 2010; McCarthy & Grant, 2024). These characteristics determine which media presentations resonate with the audience and how credibility is assigned. For instance, gender affinity effects (Dolan, 2008) — whereby audiences exhibit a preference for sources of their own gender — were observed inconsistently, suggesting a complex interplay between personal identity and stereotypes in credibility judgments (Flanagin & Metzger, 2003; Hubner & Bullock, 2024). Furthermore, age biases emerged in studies, leading to the perception of older experts as more credible. Nonetheless, this phenomenon showed to vary according to gender of the source (Weibel et al., 2008).

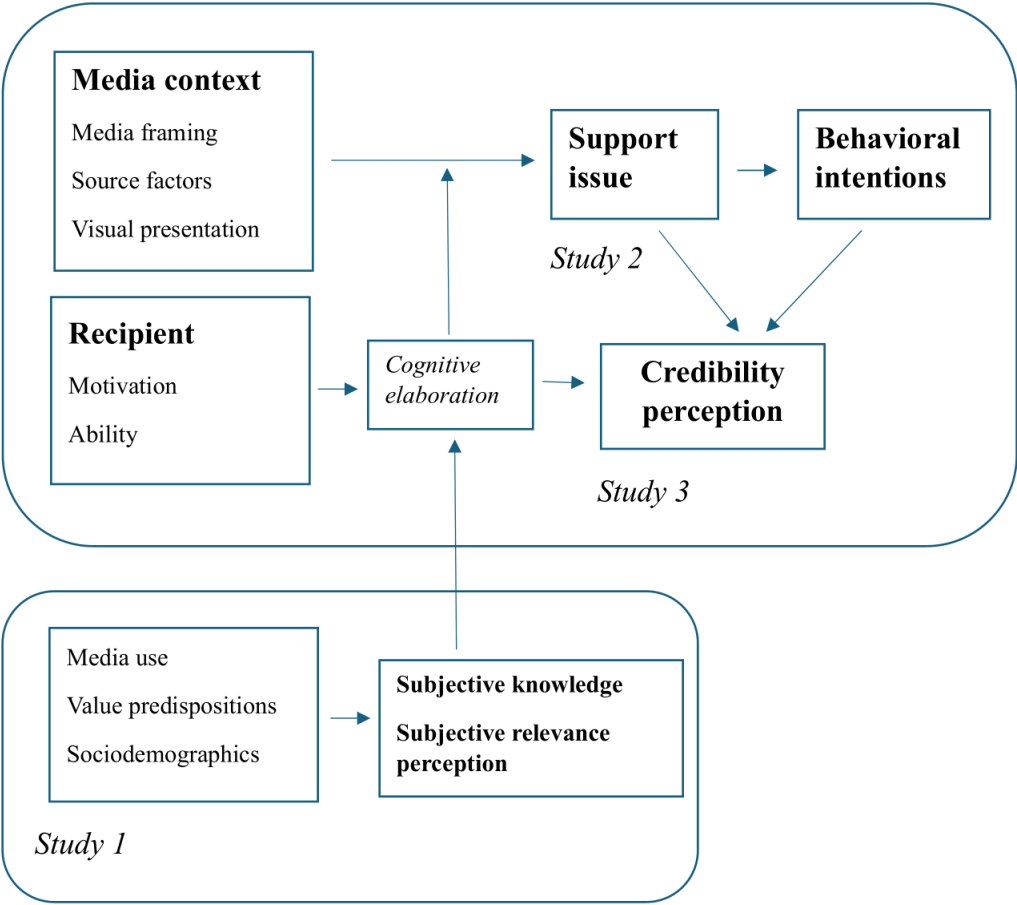
Visual elements such as infographics, maps, and animations have been demonstrated to influence audience perceptions, with static formats often perceived as more reliable than dynamic ones (N. Li et al., 2018). The credibility of the data source is also of paramount importance, with sources associated with high expertise, such as universities, being viewed as more credible than governmental or tabloid sources (Meier, 2017). Furthermore, the incorporation of visual elements into news content has been shown to compensate for deficiencies in source credibility. This suggests that visuals can function as heuristic cues that influence evaluation beyond the content itself. Although the impact of visualizations on the credibility of content has been the subject of considerable research, the visual representation of scientists themselves, particularly in mediated contexts such as social media or educational materials, has only recently received attention. Research has demonstrated that portrayals of scientists that are gendered and counter stereotypical can positively influence perceptions of trustworthiness, warmth, and competence, especially for female scientists (Good et al., 2010; Hubner & Bullock, 2024;

Jarreau et al., 2019). These effects are frequently facilitated by factors such as likability and attractiveness of the source, which have the potential to challenge or reinforce existing gender stereotypes in the domain of science communication (DeBono & Harnish, 1988; Widgery, 1974). Furthermore, facial appearance and initial impressions serve as influential peripheral cues that shape evaluations of scientific quality and interest in research, particularly among older and female viewers (Gheorghiu et al., 2017). The interplay of race and gender stereotypes also reveals substantial intersectional biases: According to Eom et al. (2025), Black female scientists receive lower ratings in terms of competence and warmth. This suggests that the impact of sociocultural prejudices is compounded, resulting in a perceived decrease in credibility.

Taken together, these findings suggest that visual representations of scientists act as peripheral cues that can enhance or diminish perceived source credibility, especially when the audience lacks the motivation or ability to engage in central (content-focused) processing. This insight is particularly salient in the context of rising public skepticism toward scientific institutions, where non-content-related cues, such as the appearance and demographics of the communicator, may disproportionately influence trust (L. König & Jucks, 2019). In this context, visual depictions of scientists may function as crucial heuristics that influence the evaluation of scientific information, particularly in circumstances involving minimal engagement (Axsom et al., 1987; Chaiken, 1980). However, it is important to note that these effects are unlikely to be uniform across diverse audiences. A plethora of studies have demonstrated that individual-level factors, including subjective knowledge and prior attitudes toward science, have been shown to moderate media credibility effects. However, as outlined in the appendix, these factors are frequently disregarded in experimental settings (see exceptions in Flanagin & Metzger, 2003; Treise et al., 2003).

As shown in Figure 18, the anticipated influence of scientists as sources in media reporting depends on factors related to their gender, age, and visual presentation. These elements are believed to contribute to the credibility perception, which is hypothesized to be influenced by the predispositions of the recipients.

Figure 18. Overview on empirical studies and variables of this dissertation



5. Study 1: Influence of Contextual and Individual Determinants

To initially obtain an understanding of the impact of pertinent determinants associated with attitude formation towards emerging technologies, the first empirical study investigated the interplay between contextual and individual factors. Chapter 5.1 provides an overview of the research questions of study 1. A survey study with a quasi-experimental research design was conducted for the purpose of investigating contextual and individual determinants. Accordingly, the methods in this study used will be explained in chapter 5.2. This includes research design, experimental manipulation, measures, data collection and sampling, and data analysis procedure. Chapter 5.3 summarizes the results of the study, and chapter 5.4 discusses the main findings and limitations of this research.

5.1. Research Questions

A study of the interaction between audience factors and media influences in shaping public perceptions of emerging technologies has revealed several significant gaps in the current understanding of the issue, as well as avenues for future investigation. It is imperative to expand the current paradigms of science communication models to address the critiques and demands highlighted in recent research. Nevertheless, a substantial critique in the domain of science communication research pertains to the absence of comprehensive theoretical models. Bucchi and Trench (2021) advanced the argument that prevailing models frequently prove inadequate in their capacity to capture the inherent complexities of science communication. In this realm, literature has underscored the necessity for more robust and nuanced theoretical frameworks that can facilitate a more profound comprehension of the interactions between science and the public (Anderson et al., 2010; Klinger et al., 2022).

Science communication models, including the deficit model and the contextual model (see chapter 2 for an exhaustive discussion on science communication models), predominantly emphasize the mechanics of information dissemination, frequently overlooking the individual audience factors that influence public attitudes (Trench, 2008). These models, however, do not take into account the mechanisms that underpin the influence of personal values, beliefs, and the media context. In contrast, the dialogue model underscores engagement and interaction, acknowledging that science communication is a reciprocal process (Einsiedel, 2008). However, the influence of the mass media in the persuasion process has often been assessed in terms of science media framing and its influence on public perceptions (Donk et al., 2011; Nisbet, 2009).

By taking these factors into consideration, the field of science communication has the potential to facilitate a more inclusive and democratic process of decision-making, thereby ensuring that the diverse interests and perspectives of the public are adequately addressed (European Commission: Directorate-General for Research and Innovation and Billgren Askwall, C., 2024; OECD, 2022). Despite the extensive scrutiny directed towards the relationship between knowledge and attitudes (Allum et al., 2008; Bauer et al., 2000), there remains a need for further empirical investigation into the formation of different types of scientific knowledge and attitudes, as this has significant implications for fostering trust in science and technology (Barnett et al., 2007; B. E. Wynne, 2006).

Knowledge as determinant of attitude formation

Since the late 1980s, scholars have increasingly focused on examining the nexus between knowledge and related attitudes (Durant et al., 1989). A prevailing consensus in the field of science communication research suggests the presence of a weak yet persistent correlation between *scientific knowledge* and *positive attitudes* towards science (see, for example Allum et al., 2008 for a review). This correlation manifests in various forms, including support for specific technologies and applications (Bauer et al., 1994; Sturgis & Allum, 2004).

However, operationalizing knowledge as a dependent variable poses challenges, such as distinguishing between objective and subjective knowledge (C.-Y. Park, 2001; Rihn et al., 2021). *Objective knowledge* has been defined as the body of knowledge that people actually possess about science or specific subjects (Brossard & Shanahan, 2006; Rihn et al., 2021). For instance, the objective knowledge in terms of genetically modified food might be assessed by asking true or false questions such as "Ordinary tomatoes do not contain genes, while genetically modified tomatoes do? (true or false)" (Allum et al., 2008, p. 44). Nonetheless, it can be argued that this approach captures factual knowledge as a narrow view of scientific literacy (see for example Miller, J., D., 1983) by relying heavily on the knowledge of scientific constructs or facts (Kahan et al., 2009; Ladwig et al., 2012).

Conversely, *subjective knowledge*, otherwise referred to as "self-perceived knowledge," has been utilized in studies as a self-reported metric to evaluate the knowledge that individuals believe they possess, irrespective of their actual knowledge (S. Lee et al., 2021; C.-Y. Park, 2001). The assessment of subjective knowledge is typically undertaken in studies that focus on constructs such as awareness, subjective informedness,

or familiarity with science or scientific issues. In this domain, scholars have contended that subjective knowledge plays a pivotal role in comprehending public attitudes, particularly concerning emerging and intricate scientific subjects (Ladwig et al., 2012; Sheetz et al., 2005; Yang et al., 2017). This assertion is predicated on the premise that audiences predominantly acquire insights into emerging technologies through media reporting, as opposed to relying on conventional textbook knowledge (C.-Y. Park, 2001).

To illuminate public attitudes towards science and emerging technologies, the European Commission has carried out Eurobarometer surveys since 1974. These surveys have focused on various aspects, including science and technology perception (2010a), views on Responsible Research and Innovation (RRI) (2013), and knowledge towards science and technology (2021c). The most recent Eurobarometer survey, conducted in 2021, revealed a noteworthy interest among respondents in scientific discoveries and technological advancements. In this regard, the survey, which encompassed 27 EU Member States and 11 non-EU countries, found that 82% of respondents expressed a high level of interest in technological developments. However, only a smaller proportion of respondents, 13%, claimed to be well informed about these issues (European Commission, 2021c).

Furthermore, a positive correlation has been demonstrated between higher levels of interest in scientific and technological developments and higher levels of perceived awareness regarding these developments (European Commission, 2013). Recent survey data has demonstrated moderate awareness of specific AI applications. For instance, 46% of surveyed US adults reported having encountered information regarding the use of AI in weather forecasting, while 33% indicated having heard or read about the use of AI in news article composition (Funk et al., 2023). Evidence of knowledge gaps was also apparent in specific areas of emerging technologies, such as nanotechnology, where 55% of respondents lacked awareness regarding those scientific developments, and synthetic biology (83% lacked awareness) (European Commission, 2010b). Public awareness of science and technology is further influenced by the channels through which people receive information (Cacciatore, Anderson, et al., 2012; Nisbet et al., 2002). Accordingly, recent survey data shows that the public's main sources of information on science and technology were television (63%), online social networks and blogs (29%), and online and printed newspapers (24%) (European Commission, 2021c).

Additionally, *subjective knowledge* regarding emerging technologies appeared to be associated with the *subjective relevance perception* of these technologies (Bauer & Bonfadelli, 2002), suggesting that a message exerts an influence on individuals due to its

connection to their personal experiences. According to the most recent Special Eurobarometer investigation, the majority of individuals surveyed (86%) indicated a positive general impact of science and technology on society. Furthermore, these respondents perceived the personal benefits of emerging technologies to outweigh the potential risks. For example, participants indicated that solar energy (92%), vaccines and the fight against infectious diseases (86%), and artificial intelligence (61%) would have a positive effect in the future (European Commission, 2021c). Since 1991, the European Commission has incorporated Eurobarometer surveys, with a particular focus on gauging public opinion regarding biotechnology within its research agenda. These investigations demonstrated that Europeans hold a favorable outlook on biotechnology, anticipating a positive impact in the future (European Commission, 2010b). Furthermore, issues related to digital technologies, such as the misuse of personal data, the propagation of false information, and the presence of unreliable online sources, have been identified as the primary personal concerns (European Commission, 2024h).

Research in the field of communication science has extensively examined the influence of individual or group-level traits on media consumption and engagement with content (Livingstone, 2003; McQuail, 1997). In this regard, Nisbet et al. (2002) identified various variables related to media influence, including exogenous factors such as age, gender, and education, which affect media use and perceptions. Antecedent endogenous variables, including media use by channel, have been demonstrated to influence factual knowledge and understanding of scientific processes. For instance, higher levels of education and elevated socio-economic status frequently coincide with a more profound interest in complex scientific subjects (Nisbet et al., 2002; Tucker-Drob et al., 2014).

The influence of social and cultural variables

Furthermore, cultural values and social norms exert a considerable influence on the formation of attitudes. A multitude of cultural factors have the potential to influence an individual's perception and comprehension of scientific and technological news media (Tucker-Drob et al., 2014). For instance, cultural attitudes toward technological advancements can impact the level of acceptance or skepticism toward new scientific developments (Horlick-Jones et al., 2012; E. M. Rogers & Shoemaker, 1971). However, individuals from cultures that prioritize environmental sustainability may demonstrate greater support for renewable energy technologies, irrespective of their level of scientific literacy (Rochyadi-Reetz et al., 2019). For instance, in societies with a history of scientific and

technological advancement, the public may be more receptive to emerging technologies, perceiving them as opportunities for progress (Lima et al., 2005). Conversely, cultures with more traditional values may view technologies such as genetic modification or artificial intelligence with suspicion, as these innovations challenge established ways of life or ethical norms (Kong, 2019).

Another salient cultural variable is the extent of technological integration within a society or its technoscientific culture (Jasanoff, 2005). This phenomenon is especially evident in the context of highly disruptive technologies, such as AI, which profoundly impact established norms in domains such as employment, privacy, and decision-making processes (Funk et al., 2023; D. Lee & Yoon, 2021). Research over the past fifteen years, particularly through Eurobarometer and other surveys, has enabled cross-cultural comparisons of public attitudes and knowledge about science across Europe, North America, and beyond (European Commission, 2021c; Funk et al., 2017; Gallup, 2021). The empirical results indicate considerable diversity in public attitudes towards science and, notably, significant variation in levels of scientific literacy among different regions.

Bauer et al. (1994) found a curvilinear relationship between the strength of the knowledge–attitude correlation at the country level and gross domestic product (GDP). Specifically, the correlation was observed to be lowest in both the most economically advanced countries and those that are least developed. Notably, the correlation between knowledge and attitudes is elevated in more industrialized countries (e.g., Denmark and Germany) in comparison to less industrialized countries (e.g., Portugal or Greece). However, as demonstrated by Allum et al. (2008), in a meta-analytic approach involving the analysis of nationally representative surveys on PUS conducted since 1989 in 40 countries, a modest positive correlation between general attitudes toward science and general knowledge of scientific facts was revealed. This variation could only be marginally attributed to country-level differences, but rather to the specific scientific field. To sum up, the initial research objective of study 1 is to ascertain the specific impact of the aforementioned variables on the dependent variables of subjective knowledge and subjective relevance perception. To this end, the study will consider the influence of differences between individuals, such as sociodemographics and media use, the context of technology news reporting, and respondents' country of origin:

RQ1.1: Which factor contributes more to the formation of subjective knowledge and subjective relevance perception toward emerging technologies, differences at the level of persons, the level of technology topics of newspaper stimuli, or between countries?

Notwithstanding the overall positive correlation between scientific literacy and attitudes, the influence of scientific literacy on attitudes can vary depending on the context and the specific technology in question (Allum et al., 2008). In the context of highly controversial technologies, such as genetically modified organisms (GMOs) or nuclear energy, higher scientific literacy does not invariably translate into increased support. Alternatively, individuals may utilize their knowledge to reinforce preexisting beliefs (Ho et al., 2008; Mielby et al., 2013). A comparative analysis of the impact of diverse technological modalities on the subjective knowledge and relevance of recipients is lacking. There is evidence that, for example, public knowledge about nanotechnology (Akin et al., 2017; Vandermoere et al., 2009) or biotechnology (Hallman et al., 2003; Shanahan et al., 2001) tends to be low. It is reasonable to assume that specific groups or clusters of technologies, such as production technologies, are less likely to be well known compared to technologies which are more tangible in everyday life, such as energy technologies (Daamen et al., 1990). Furthermore, given the rapid development in technological advancements, recent investigations on this comparative view on perceptions of different technology areas are lacking, especially within the context of science news reporting. In order to discern variations among technology groups in the evaluation of these emerging technologies, the following inquiry is posed:

RQ1.2: Are there differences in subjective knowledge and subjective relevance perception across different types of technologies?

Information behavior and information sources

Since the 1990s, significant shifts in the media environment have profoundly altered the nature of public engagement with science, moving away from the view of a passive mass communication consumption toward interactive, audience-driven models (Brossard et al., 2019; Schäfer et al., 2018). A critical challenge in integrating media effects with science communication models is the context of communication, which in turn affects how audiences interact with science communication. This evolution is reflected in a shift toward collective audience approaches, which entail the tailoring of communication strategies to

specific audience groups based on their unique characteristics, beliefs, and behaviors (Anderson et al., 2010; Brossard, 2013). In the context of audience segmentation analysis, a range of variables have been taken into consideration, including but not limited to personal values, scientific awareness, attitudes toward science, and behavioral tendencies (Klinger et al., 2022; Longnecker, 2023).

Additionally, media preferences and habits play a pivotal role in the efficacy of science communication strategies, as patterns of media usage, for example frequency and type of consumption, influence engagement with scientific content (Nisbet et al., 2002). Therefore, media outlets, including television, radio, newspapers, social media, and websites, possess distinct characteristics that influence the manner in which science is communicated to the public (H. P. Peters et al., 2014). For instance, social media provides interactive elements and real-time updates, while television offers in-depth documentaries and visual storytelling (Howell & Brossard, 2020; Tang et al., 2021). Recent Eurobarometer investigations on Science and Technology revealed that the public primarily derives scientific information from television, and also to a considerable amount from online news and social media sources (European Commission, 2013, 2021c). Moreover, the level of subjective knowledge has been demonstrated to be associated with the utilization of information sources (Nisbet et al., 2002; D. A. Scheufele & Lewenstein, 2005; Takahashi & Tandoc, 2016). Higher levels of subjective knowledge have been observed to correspond with the use of science newspapers and online news sources, while lower levels have been associated with the use of television (Nisbet et al., 2002). Furthermore, social circumstances, including influences from family, peer groups, and community values, shape media preferences and content engagement (Nisbet & Scheufele, 2009). Consequently, citizens interact with science largely through conversations with family or friends (55%) (European Commission, 2021c). Therefore, this study will evaluate the impact of the use of different information sources in the context of emerging technologies:

RQ1.3: How is the use of information sources, including mass media and interpersonal communication, related to subjective knowledge and subjective relevance perception regarding emerging technologies?

Cross-national differences in information behavior

J. Miller et al. (1997) further advanced the field by comparing attitudes and knowledge about science and technology across Europe, the United States, Canada and Japan. Their

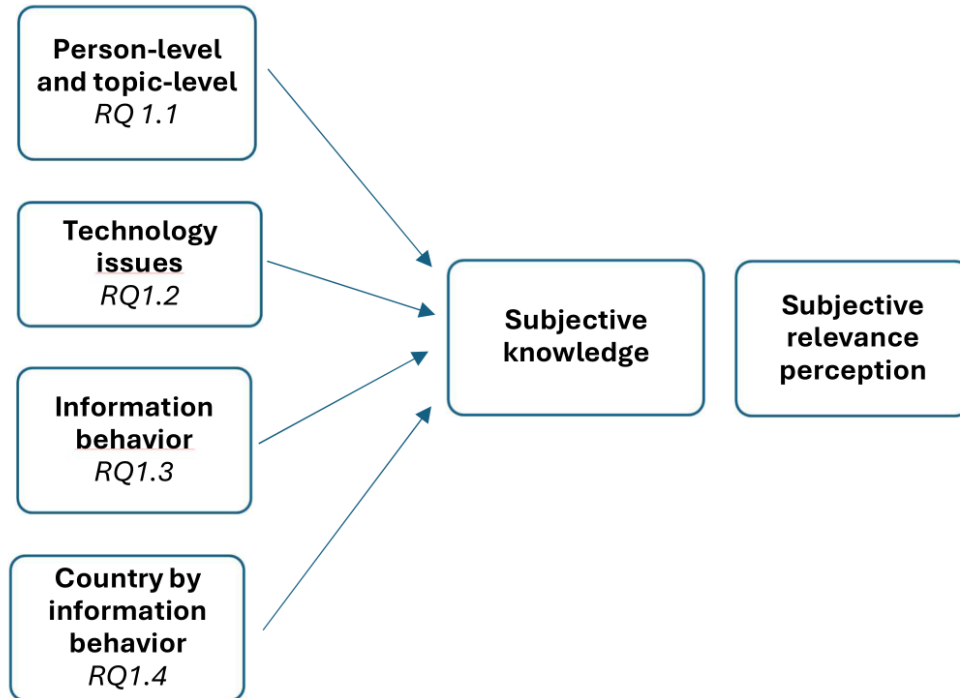
findings indicated that cultural context exerts a substantial influence on public perception and understanding of scientific subjects, thereby suggesting that educational systems, media coverage, and societal values collectively shape the public's perception of science. In their meta-analysis, Allum et al. (2008) also emphasized the importance of media in shaping public understanding of science. The conclusion drawn from this analysis showed that nations with robust public service broadcasting systems that prioritize science and education tend to have populations that are more knowledgeable about scientific issues. Conversely, countries with restricted or sensationalist media exposure frequently exhibit diminished levels of public comprehension (Allum et al., 2008).

The prevailing emphasis in science communication research on Anglophone countries can be argued to restrict findings to a single linguistic and cultural domain, thus hindering their generalizability (Guenther & Joubert, 2017). In addition, the media content can be adapted to aligning with local or global perspectives, thereby influencing its relevance and impact. Local media outlets tend to prioritize issues that are pertinent to specific communities, while global media outlets tend to cover more universal scientific subjects (McQuail, 1992). It is plausible that these discrepancies are even more pronounced when considering countries outside the European Union (Hallin & Mancini, 2004). As Schäfer (2017) has suggested, the manner in which scientific issues are covered by the media varies between the United States, the United Kingdom, and Germany. Nonetheless, there is a dearth of research investigating the evaluation of technology issues in these subpopulations and its differences in media use related to emerging technologies. The following research question is thus proposed:

RQ1.4: Are there cross-country differences in the effect of information sources on subjective knowledge and subjective relevance perception regarding emerging technologies?

As displayed in Figure 19, the first empirical study aims to provide a wider perspective on the recipient's evaluations of a selection of both well-known and lesser-known technologies in the public sphere, as conveyed by the media. Secondly, the study aims to illuminate the contextual and individual determinants of subjective knowledge and subjective relevance regarding emerging technologies (*RQ1.1*). Moreover, the present study sets out to investigate the influence of technology type (*RQ1.2*), information behavior (*RQ1.3*), and country background related to information behavior (*RQ1.4*) as predictors of subjective knowledge and subjective relevance in terms of emerging technologies.

Figure 19. Overview on determinants and outcomes regarding the research questions to the evaluation of emerging technologies for study 1



5.2 Methods

The objective of the present section is to provide a comprehensive review of the methodological decisions that were specifically relevant to the conduction of the initial study. These decisions pertain to the study's research design, the experimental manipulation, the procedure and measures, the sample and statistical power, and the data analysis procedure.

5.2.1 Research Design

A stimulus-within-block design within a survey framework was used to conduct the first study on contextual and individual factors influencing attitudes toward emerging technologies. Based on previous research that identified determinants of attitudes toward technology-related issues, this study examined the impact of these factors. To do so, a cross-sectional online survey was implemented. This approach enabled a quantitative description of attitudes and allowed testing for associations among variables, with the aim of

generalizing the findings from the sample to the broader population (see for example Creswell & Creswell, 2018; Fowler, 2014). The survey was carried out across three countries. Given the investigative objective to examine relationships between variables, such as the association between recipients' media use or their country of origin and their subjective knowledge about emerging technologies, these variables were considered as naturally occurring groups of recipients that were not systematically manipulated in the study (Campbell & Stanley, 1967). However, a purely survey-based approach would be constrained in assessing attitudes concerning the evaluation of a broad range of technology issues.

In this study, an experimental approach was employed, with the groups of emerging technologies as the sole experimental factor systematically manipulated. This was achieved through a *counterbalanced stimulus-within-block design*, in which "the full stimulus sample is divided into a smaller number of comparable lists or blocks, and each participant is randomly assigned to receive only one of these blocks" (Westfall et al., 2014, 16). According to Westfall et al. (2014), stimulus-within-block designs offer greater statistical power compared to fully crossed designs, where every respondent answers the same stimulus block. This design also enhances time efficiency for participants (Westfall et al., 2014), serving the aim of this study to test a large number of technology issues.

Therefore, the research design for study 1 involved the random assignment of participants to blocks, with each block representing a between-subjects factor, corresponding to eight blocks of technology issues. Furthermore, the newspaper articles embedded the technology issues as an experimental factor which was realized in employing repeated-measurements *within-subjects* for the factor of technology issues where each participant was exposed to four newspaper articles on different technology issues. This procedure allowed a resource-efficient data collection with comparably fewer participants than for experimental designs with stimulus manipulations between-subjects where participants are exposed to one newspaper article to reach the same statistical power (Greenwald, 1976). Moreover, by employing within-person measurements, the variability in the data is reduced, making it easier to detect a true effect of the experimental manipulation, because when each subject provides data for several treatments, as Greenwald (1976) notes, the subject may serve "as his own control" in comparisons among treatment effects (p.315).

The potential pitfalls of this within-persons-measurement procedure have been described as *contextual effects* (Poulton, 1973), *carryover effects* among treatments

(Greenwald, 1976), or *practice effects*⁵⁰ and *participant fatigue* (Creswell & Creswell, 2018; Greenwald, 1976). These factors were addressed in study 1 through the implementation of counterbalancing techniques, which ensured that no specific order of stimulus presentation was employed (Brooks, 2012). To avoid potential carryover effects (see Westfall et al., 2014), which could occur if participants answered questions about the same technology or group of technologies twice, each participant was randomly assigned to one of the blocks. A pilot study was conducted to ascertain that the number of stimuli and the length of the survey questionnaire were appropriate and manageable for the participants.

For the initial study, the counterbalanced stimuli-within-block design comprised 4 (*technology groups*) $\times$ 8 (*distinct blocks of technology issues*). This design culminated in a total of 32 newspaper articles addressing technology issues, systematically divided into eight blocks, with each block containing four technology issues related to the four distinct technology groups specified in chapter 2.1. In the online questionnaire, these technology blocks were presented as newspaper stimuli, with each participant evaluating one of these blocks, which contained a set of four technologies — one from each of the four groups of emerging technologies.

Table 6 details the block conditions, with each row representing a list of four newspaper conditions assigned to participants for their responses. Additionally, the four newspaper articles on technology issues were randomized to balance out order effects. To illustrate, one participant could be assigned to row four of the condition blocks and be asked about 3D printing (production technology), robotics (digital technology), electric vehicles (energy and environmental technology), and medical imaging (biotechnology) in a varying order. The resultant dataset, comprising 1,777 observations, encompassed 501 participants, each responding to distinct technology-related stimuli within the designated order.

⁵⁰ Such effects may arise due to experimental conditions affecting the response to other conditions, however practice and sensitization effects are less common to be expected when examining short-term effects of treatments that have no persistent effects that carry over to subsequent conditions (Greenwald, 1976).

Table 6. Conditions of the counterbalanced 4x8 stimuli-within-block design for study 1

Condition	Production Technologies	Digital Technologies	Energy and Environmental Technologies	Biotechnologies
1	Nanotechnology	Photonics	Smart grid	Personalized medicine
2	Lightweighting	Cloud computing	Precision agriculture (PA)	Stem-cell therapy
3	Process manufacturing	Blockchain	Unmanned aerial vehicle (UAV)	Remote patient monitoring (RPM)
4	3D printing	Robotics	Electric vehicles	Medical imaging
5	Two-dimensional (2D) materials	Grid computing	Biofuel	Regenerative medicine
6	Smart materials	Artificial intelligence (AI)	Fuel cell	Neurotechnology
7	Functionally graded materials (FGMs)	Internet of Things (IoT)	Wind turbine	Biosensor
8	High-performance plastics	Big data	Tidal energy	Synthetic biology

$N = 501$, $n = 1,777$ (respondent x technology) observations. The rows represent technology blocks, and each participant was randomly assigned to respond to one of eight stimulus blocks. Each block contained four stimuli or newspaper texts on technology issues in a randomized order.

5.2.2 Experimental Manipulation

As the objective of this investigation was to identify participants subjective attitudes towards emerging technologies, chapter 2 highlighted the societal and economic potential of emerging technologies as key components of their relevance. To identify relevant technologies in the context of attitude formation in recipients, chapter 2.1 described technology clusters based on policy papers (European Commission, 2009, 2018c; OECD, 2016). According to the proposed typology, technology issues were categorized into the following areas: *digital technologies*, *biotechnologies*, *energy and environmental technologies*,

and *production technologies*. However, as previously mentioned, it is important to note that these categories should not be regarded as non-overlapping entities. For instance, personalized medicine could also be categorized as biotechnology, with an emphasis on digital methods (World Health Organization, 2021). Rather, this typology served as a reference point for analyzing differences in respondents' technological attitudes. To provide a comprehensive empirical foundation for the evaluation of emerging technologies, the suggested overview of technology clusters and specific technologies (see chapter 2.1) was employed for the initial study, comprising 32 distinct technologies. The newspaper stimuli for the study on technology evaluation were created on the basis of lexica or Wikipedia articles, to provide definitions, basic explanations, and facts about the 32 technologies (see [online appendix](#) for the survey questionnaire). As Figure 20 shows, the newspaper headline introduced the technology issues to the reader (i.e., nanotechnology), and the newspaper texts were concise, ranging from three to five lines in length. Moreover, the newspaper design was kept simple and neutral, without indicating a specific news outlet.

Figure 20. Stimulimaterial newspaper condition for study 1

Nanotechnology

Nanotechnology ("nanotech") is manipulation of matter on an atomic, molecular, and supramolecular scale. Nanotechnology relates to the particular technological goal of precisely manipulating atoms and molecules for fabrication of macroscale products, also now referred to as molecular nanotechnology. The technology can be defined as the manipulation of matter with at least one dimension sized from 1 to 100 nanometers.

Example of the newspaper condition of nanotechnology

5.2.3 Procedure and Measures

The present study was conducted using an online survey implemented through the survey platform SoSci Survey (2024). At the beginning of the questionnaire, respondents were informed about the study's purpose, data collection procedures, and regulations, and they confirmed their participation. The survey was designed to take between 10 and 15 minutes to complete, and this time frame was determined through two individuals during pretests conducted prior to data collection.⁵¹ At the onset of the survey, participants were prompted to provide sociodemographic information, including their gender, age, and

⁵¹ To ensure thoughtful responses to the online questionnaire, the study sample excluded respondents who completed the questionnaire in under five minutes.

educational background. Furthermore, the country of residence was assessed by using a filter variable in the questionnaire, which tracked the three different country links employed for the access panel by Bilendi & Respondi (Bilendi & Respondi, 2024). Moreover, the experimental procedure entailed the manipulation of technology issues in an online questionnaire. Participants were instructed to read newspaper articles on four technology issues and subsequently answered items measuring subjective knowledge, subjective personal relevance, and subjective societal relevance perceptions regarding the technology issues. The operationalization of the relevant determinants and outcomes, as well as the relevant statistics, will be outlined in the following sections.

Subjective knowledge of emerging technologies

In line with other studies (European Commission, 2013; Yang et al., 2017), respondents were asked for their self-reported subjective knowledge about the technology they encountered before in the survey which was realized by using a single-item measure on a 7-point-scale from 1 = *strongly disagree* – 7 = *strongly agree* (“In general I do feel well informed about...”). The descriptive statistics for subjective knowledge regarding emerging technologies are presented in Table 7. Participants rated their *subjective knowledge of emerging technologies* on a 7-point scale, with a mean score of $M = 3.31$ ($SD = 1.92$), indicating a moderate level of self-reported knowledge. ICC values for subjective knowledge showed moderate variability at the individual level (.40), low variability at the technology stimulus level (.14), and low variability at the country level (.10).

Subjective relevance perception of emerging technologies

As indicated by several investigations, the dimensions of relevance perception concerning the point of reference for the individual or society have proven to be of considerable importance for science and technology perception (Akin et al., 2017; European Commission, 2010a, 2010b; Kahlor & Rosenthal, 2009). The subjective relevance perception of the issue was investigated in the first study by two items, as relating to subjective personal relevance perception (adopted by Akin et al., 2017) and subjective relevance perception on the societal level (adopted by the European Commission, 2010b). Concerning personal relevance perception, the item “This technology will have a big impact on my personal life in the future” on a 7-point scale ranging from 1 = *strongly disagree* – 7 = *strongly agree*, was used. Overall, the mean rating for personal relevance perception was $M = 4.16$ ($SD = 1.88$), suggesting that participants believe these technologies will have a significant

impact on their personal lives in the future. For societal relevance perception, the mean score was higher at $M = 5.01$ ($SD = 1.69$), indicating that participants view emerging technologies as likely to have a considerable impact on society. Furthermore, the ICCs for subjective personal relevance indicated moderate variability on the person level ($ICC = 0.41$) and low variability on the level of technology stimuli ($ICC = 0.07$), and on the level of countries ($ICC = 0.14$). This pattern was also reflected in the perception of societal personal relevance (person level $ICC = 0.43$, technology stimuli $ICC = 0.08$, countries $ICC = 0.10$).

Information behavior

In order to investigate differences between the different sources of information used by audiences in relation to emerging technologies, the amount of information participants received from *the media* or *interpersonal communication* was measured according to respondents' self-assessment. In line with a study by C. Lee and Scheufele (2006) on the influence of media use on scientific knowledge and related attitudes, this was done using a single item for each source of information, asking respondents to rate on a 7-point scale how much information related to the specific technology they received from *media sources, including television, newspapers, or online sources*, e.g., "In my everyday life, I get a lot of information related to nanotechnology from television". In addition, the self-reported amount of information about emerging technologies received from *interpersonal communication* was assessed in the same way as for media sources by asking two items related to conversations with friends, family, and peers and conversations with experts. The information behavior measures were scored on a 7-point scale from 1 = strongly disagree - 7 = strongly agree.

As indicated in Table 7, mean scores for *information behavior* variables were as follows: $M = 2.82$ ($SD = 1.90$) for television, $M = 2.57$ ($SD = 1.83$) for newspapers, $M = 3.17$ ($SD = 2.01$) for online sources, $M = 2.63$ ($SD = 1.89$) for conversations with friends and family, and $M = 2.46$ ($SD = 1.87$) for conversations with experts. The ICCs for the various sources of information showed some variability on the person level, with values of $ICC = 0.46$ for television, $ICC = 0.49$ for newspapers, $ICC = 0.43$ for online sources, $ICC = 0.45$ for conversations with friends and family, and $ICC = 0.49$ for conversations with experts. For these sources, the ICCs at the technology stimuli and country levels ranged from 0.06 to 0.14, indicating low variability at these levels.

Table 7. Overview on the operationalization of measures and statistics for study 1

Construct	Statistics				
	<i>M</i>	<i>SD</i>	<i>ICC</i> (<i>person</i>)	<i>ICC</i> (<i>tech</i>)	<i>ICC</i> (<i>country</i>)
<i>Subjective knowledge of emerging technologies</i> (based on European Commission, 2013; Yang et al., 2017)					
(1) In general, I do feel well informed about this technology.	3.31	1.92	.40	.14	.10
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)					
<i>Subjective relevance perception regarding emerging technologies</i> (based on Akin et al., 2017; European Commission, 2010b)					
Personal relevance					
(1) This technology will have a big impact on my personal life in the future.	4.16	1.88	.41	.07	.14
Societal relevance					
(1) This technology will have a big impact on society in the future.	5.01	1.69	.43	.08	.10
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)					
<i>Information behavior regarding emerging technologies</i> (based on C. Lee & Scheufele, 2006)					
In my everydaylife, I get a lot of information related to this technology from					
(1) Television	2.82	1.90	.46	.11	.09
(2) Newspapers	2.57	1.83	.49	.09	.08
(3) Online sources	3.17	2.01	.43	.12	.11
(4) Conversations with friends, family and peers	2.63	1.89	.45	.09	.13
(5) Conversations with experts	2.46	1.87	.49	.06	.14
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)					

5.2.4 Sample and Statistical Power

The initial study was designed to account for country-specific differences, as it was anticipated that newspaper content pertaining to emerging technologies would be evaluated differently by recipients due to regional characteristics (Allum et al., 2008). As recommended by the National Science Board (2018), a knowledge- and technology-intensive

industry (KTI)⁵² was selected for the sample countries. As a reference point, the R&D intensity was used as the ratio of a country's or an organization's research and development (R&D) expenditure to its gross domestic product (GDP) (National Science Board, 2018). Global R&D activity was as of 2018 concentrated in North America, Europe, and the East and Southeast of Asia. As shown in the National Science Board (2018) Science and Engineering indicators, the United States accounted for 38% of the GDP allocated to Knowledge and Technology Industries (KTI) among individual countries (National Science Board, 2018). The United States has consistently demonstrated its dominance in research and development (R&D) investment⁵³, with a remarkable \$667 billion invested in 2019 constituting approximately 3.1% of its gross domestic product (GDP) (NSF, 2022). In 2019, the Member States of the European Union (EU) spent over €306 billion on R&D, while the R&D intensity, stood at 2.19% in 2019 (eurostat, 2020), for example for Germany with an R&D intensity exceeding 3% of GDP in 2019 (eurostat, 2020). Moreover, the United Kingdom's total net expenditure on R&D and knowledge transfer activities amounted to £13.4 billion in 2019, constituting 0.6% of its GDP (Office for National Statistics, 2021). Accordingly, the study's sub-samples included the United States, Germany, and the United Kingdom⁵⁴ to ensure the representation of comparable economic significance for emerging technologies.

With regard to generalizability of the findings to other participants (Shadish, 2001), the objective of this study was to reflect the demographics of the general population as closely as possible to detect differences in media usage across countries. To this end, the decision was made to not employ a convenience sample, such as university students (Wild et al., 2022), but rather to recruit participants through a panel service provider. This approach was adopted to ensure the diversity of the samples in terms of

52 Knowledge- and technology-intensive (KTI) industries, are divided into three main areas. The first is knowledge-intensive (KI) services, which include both commercial services such as business, financial, and information services, and public services such as education and health. The second category is high-technology (HT) manufacturing, which covers sectors such as aircraft and spacecraft, communications and semiconductors, computers, pharmaceuticals, and testing, measuring, and control instruments. Moreover, the third category is medium-high technology (MHT) manufacturing, which comprises motor vehicles and parts, electrical machinery, general machinery and equipment, chemicals (excluding pharmaceuticals), and other forms of transportation equipment (National Science Board, 2018).

53 Although the United States invests far more in R&D than any other individual country, several other, smaller economies have greater R&D intensity, such as for example Sweden (eurostat, 2020).

54 The United Kingdom was selected as a sub-sample due to its active role in global Knowledge- and Technology-Intensive (KTI) industries (National Science Board, 2018), alongside its strong academic research tradition and influence in international policy debates on emerging technologies (Gregory & Lock, 2008). The inclusion of the UK as a sub-study was also pragmatically justifiable. This is primarily because the research panel of Respondi & Bilendi was based in the UK, thereby facilitating easier access to regional data and logistical coordination for this study.

gender, age, and education. Adopting quotas in the recruitment process was instrumental in achieving this objective. The recruitment of participants was conducted from February 10 to February 20, 2020, by the panel service Bilendi & Respondi (Bilendi & Respondi, 2024). With the goal of achieving balanced quotas for distribution by country, the sampling strategy aimed to ensure equitable representation of individuals from diverse formal education levels (low, medium, and high) and genders across all participating countries.

Calculation of statistical power

Statistical power is a critical consideration in study design to ensure that experimental manipulations are powerful enough to detect true effects while minimizing unnecessary participant recruitment and resource use (Westfall et al., 2014). In statistical terms, statistical power refers to the probability of correctly rejecting the null hypothesis when a true effect exists (J. Cohen, 2013). A typical recommendation for empirical studies is to aim for a power level of 0.80, meaning that there is an 80% chance of detecting a true effect if it exists. This minimizes the risk of type II errors, or false negatives, which occur when a test incorrectly indicates the absence of an effect that is in fact present (J. Cohen, 2013).

Several factors influence statistical power, with *sample size* being one of the most significant. A larger sample size reduces variability, increases precision, and makes it easier to detect statistically significant differences (J. Cohen, 2013). Another critical factor is *effect size* — the magnitude of the relationship between variables. Larger effect sizes require smaller samples to be detectable, while smaller effect sizes necessitate larger samples. In media studies, where effects such as of framing may be subtle, ensuring adequate power to detect these smaller effects is essential (J. Cohen, 2013; Faul et al., 2007). The *alpha level* (typically set at 0.05) also influences power. A stricter alpha (e.g., 0.01) reduces power because it requires stronger evidence to reject the null hypothesis, whereas a higher alpha (e.g., 0.10) increases power but raises the risk of Type I errors (false positives) (J. Cohen, 2013). Overall, the repeated within-subject measures of stimuli materials used in this study required fewer participants than between-subject designs to achieve the same level of power (Westfall et al., 2014). In general, within-subject designs increase sensitivity to treatment effects by controlling for within-subject variability, which can increase power (Greenwald, 1976). However, it should be noted that participants were exposed to multiple conditions across different trials, thereby increasing the complexity of the analysis (Westfall et al., 2014). This aspect is further compounded by the

correlation structures and interactions that need to be accounted for (Faul et al., 2007). Conversely, research designs employing within-person measurements entail the presentation of multiple experimental conditions (e.g., various technology issues in this study), thus necessitating a more extensive and elaborate set of stimuli to effectively capture interactions compared to between-subjects-designs (Judd et al., 2012).

As suggested in the literature, *power analysis* can be conducted during the study design phase to estimate the required sample size, balancing the need to avoid underpowered studies which leads to inconclusive results and overpowered studies leading to unnecessary recruitment of participants (J. Cohen, 2013). In *a priori power analysis* (see J. Cohen, 2013), the sample size N is calculated as a function of the required power level, the prespecified significance level (α), and the population effect size to be detected with probability $1 - \beta$ (Faul et al., 2007). Using G*Power (see Faul et al., 2007), an *a priori* power analysis was performed for a repeated-measures ANOVA with within-interaction, where the grouping factor was defined as the eight technology blocks and the four technology stimulus texts as the within-factor. For an estimated effect size of $f = 0.25$ with 80% power and an alpha level of 0.05, a total sample size of 56 participants was targeted. Additionally, for an effect size of $f = 0.1$ (80% power, alpha level 0.05), a total sample size of 280 participants would be required. For a comparable between-subjects design with 32 groups of technology issues, the total sample size would be 271 participants to detect an effect size of $f = 0.25$. Assuming a smaller effect size ($f = 0.1$), the between-subjects design would require a total sample size of 2,448 participants. Therefore, it was decided that study 1 would require at least 300 participants to detect a small effect size at 80% power, which was achieved by recruiting 537 participants in the initial data collection.

In total, data were collected from $n = 537$ respondents, after data cleaning with excluding cases that cancelled their participation in the questionnaire before answering the dependent variables or did not provide sufficient sociodemographic information, $N = 501$ respondents remained in the sample. In addition, for the analysis of subjective societal relevance perception, $n = 461$ participants were included with complete responses, and for the assessment of subjective personal relevance perception, $n = 466$ participants were included with complete responses. As shown in Table 8, of the final sample of 501 respondents, 164 were from the United States, 174 were from the United Kingdom, and 163 were from Germany. Of the final sample, 53.5% of respondents were male, 46.1% were female, and 0.4% identified as non-binary. The age of the sample ranged from 18 to 87

years ($M = 48.4$ years, $SD = 16.20$). In terms of educational background, 28.0% of the sample did not have a high school diploma, 38.3% had a high school diploma, and 33.7% had a college degree.

Table 8. Sociodemographics of the sample for study 1 on the influence of contextual and individual determinants

Sample details	$N = 501$	
	Frequency	Percentage
Gender		
Male	268	53.5%
Female	231	46.1%
Non-binary	2	0.4%
Age		
18-25	50	10.0%
26-35	77	15.4%
36-45	86	17.1%
46-55	103	20.6%
56-65	97	19.3%
>66	88	17.6%
Education		
No education diploma	140	28.0%
High School	192	38.3%
University Degree	164	32.7%
PhD	5	1.0%
Country of residence		
United Kingdom	174	34.7%
United States (USA)	164	32.7%
Germany	163	32.5%

5.2.5 Data Analysis

In the following sections, the mixed-effects model data structure is described as an approach to manage the repeated measurements for this study within participants and between experimental stimuli (see for example Baayen et al., 2008). Overall, the application of mixed-effects models in the investigations enhanced the rigor of the analysis by accounting for the complexities inherent in repeated measures and the variability introduced by different technology stimuli (Barr, 2013).

Mixed effects data structure

Mixed-effects models were employed for data analysis to incorporate both fixed and random effects, thereby effectively addressing the grouped data structure (Gelman & Hill, 2006). As Barr (2013) noted, recognizing the variability among sampling units, such as participants and stimuli, enables researchers to model dependency within the data effectively. In comparison to conventional multiple regression and analysis of variance (ANOVA) methodologies, mixed-effects regression offers enhanced precision in prediction by reducing error variance and this enhanced accuracy facilitates the model's capacity to detect subtle effects, account for data dependencies, and demonstrates greater flexibility in managing missing data (Baayen et al., 2008; Judd et al., 2017).

In multilevel modeling with, a stepwise procedure with using a null model (also known as an intercept-only model) has been recommended to account for multiple sources of variance without including predictors (Hox et al., 2017). In this study, responses were linked to participants, newspaper articles about emerging technologies, and countries. Each participant rated four different news articles, and each article was evaluated by multiple participants who originate from different countries. Intraclass correlation coefficients (ICCs) were calculated from the null model for each random factor to indicate the proportion of variance attributable to that factor (Hox et al., 2017). A high ICC at the article level means that differences between articles explain a large portion of the variance. This suggests article-specific characteristics, such as the topic shapes responses. A low ICC, on the other hand, indicates that differences between articles contribute little to the overall variance. In this case, responses vary more within the same article across participants. Similarly, a high ICC at the person level indicates that stable individual characteristics, such as demographics, attitudes, or prior knowledge, account for much of the variance. As a result, responses are consistent across articles for the same person. A low ICC, on the other hand, suggests that individual differences play a smaller role, with responses varying substantially across different articles. A high ICC at the country level suggests that systematic differences between countries explain a considerable proportion of the variance and point to cultural or contextual effects. Conversely, a low ICC indicates that country membership contributes little to the variance and that responses are similar across countries.

Literature distinguished between fixed and random effects, especially appropriate for complex research designs. Fixed effects are used to model average trends, while random effects account for the variability of these trends across levels of a grouping factor

(e.g., participants or items) (Brown, 2021). For instance, Baayen et al. (2008) demonstrated how mixed-effects models can effectively analyze experimental designs with crossed random effects for both participants and stimuli, alongside treatment variables that vary within or between participants and/or stimuli. The inclusion of random effects in modeling, as discussed by Brown (2021), addresses the non-independence problem inherent in multiple regression. In traditional multiple regression models, participants may respond differently to the same stimuli, which violates the assumption of independent observations (Brown, 2021). Random intercepts and random slopes allow the statistical model to account for deviations from the mean response and were accounted for in study 1, thereby addressing and resolving the aforementioned issue.

The approach of treating stimuli as a source of variance in studies of participants' responses to different stimuli is well documented in the literature, as for example Westfall et al. (2014) discussed the importance of considering both participants and stimuli as random factors in experimental designs. They emphasized that ignoring stimulus variation can lead to substantial biases and advocate for the use of mixed models to analyze data with crossed random factors, which provides a more accurate representation of underlying effects (Westfall et al., 2014). In study 1, the selected stimulus materials were treated as random factors to represent a broader theoretical sample of relevant texts about emerging technologies (Judd et al., 2012; Westfall et al., 2014). Consequently, the variability attributable to multiple technology stimuli can be anticipated, as respondents may possess disparate levels of knowledge regarding the presented technologies, thus substantiating the treatment as a source of variability (Westfall et al., 2014). Participants and countries were also modeled as random effects, with participants accounting for stable individual differences in responses (e.g., prior knowledge or attitudes) and countries capturing systematic cultural or contextual influences on responses. Furthermore, random slopes for information behavior by country were included in the models (see Bates et al., 2015 for fitting mixed models with random intercepts and random slopes), positing that the relationship between information behavior and outcomes might vary across countries.

Data analysis plan

Linear mixed-effects models were conducted using the *lme4* package in R (Bates et al., 2015) for data analysis. As the research questions involved three separate outcome variables, comparable models with the same predictor variables for each outcome were estimated. All of the estimated statistical models are included in the [online appendix](#).

Figure 21 shows the stepwise data analysis procedure for the mixed model data structure of study 1. As a preliminary step, random intercept only models (see Bates et al., 2015) were estimated, including random intercepts for participants, the 32 technology stimuli, and, country origin of participants. This approach was consistent with *RQ1.1*, recognizing that there may be systematic differences in subjective knowledge and subjective relevance perception between individual participants, technologies, and countries. These unconditional models were used to examine how the total variance of the dependent variable is distributed across the grouping variables. The distribution of variance is quantified by calculating the intraclass correlation coefficient (ICC), which estimates "the proportion of the variance explained by the grouping structure in the population" (Hox, 2002, p. 15). Therefore, the ICC was calculated by dividing the between-group-variance (random intercept variance) by the total variance (i.e., the sum of between-group-variance and within-group (residual) variance) (Rdocumentation, n.d.). Additionally, the null model served as a baseline for model comparisons, enabling the evaluation of whether adding predictors meaningfully improve model fit. A substantial ICC⁵⁵ indicates that a meaningful portion of variance is attributable to the grouping structure, supporting the appropriateness of multilevel modeling for these data (Hox, 2002).

Following the suggestion of *RQ1.2*, the *grouping of technologies* into thematic clusters (as detailed in chapter 2.1) was included as a fixed effect in the model to predict subjective knowledge and subjective relevance perception regarding emerging technologies (see Figure 21). The rationale behind specifying technology groups as fixed effects in this instance was that they represented categorical levels to be regarded as "exhaustive," with effects presumed to be constant across diverse contexts or studies (Judd et al., 2012, p. 55). Modeling these grouping levels as fixed effects enabled the model to estimate and test the average impact of belonging to a specific technology group on the dependent variables such as subjective knowledge, while accounting for random effects related to individuals, technology stimuli, and country backgrounds. The following step involved the prediction of outcomes, which employed the same model structure as the

⁵⁵ To interpret ICC values, it is essential to note that if the unwanted variance is equal to or greater than the variance of interest (e.g., between-subject variance), the reliability of the method can be considered poor. In such cases, the ICC has a value below 0.5 (Liljequist et al., 2019). Conversely, ICC values exceeding 0.8 or 0.9 are often considered an indication of good or excellent reliability in existing research, though this depends on the context of the study (Koo & Li, 2016; Liljequist et al., 2019).

initial model but incorporated *person-level variables* (gender, age, education) at the individual level as additional fixed effects attributable to these demographic factors (see Figure 21, step 2).

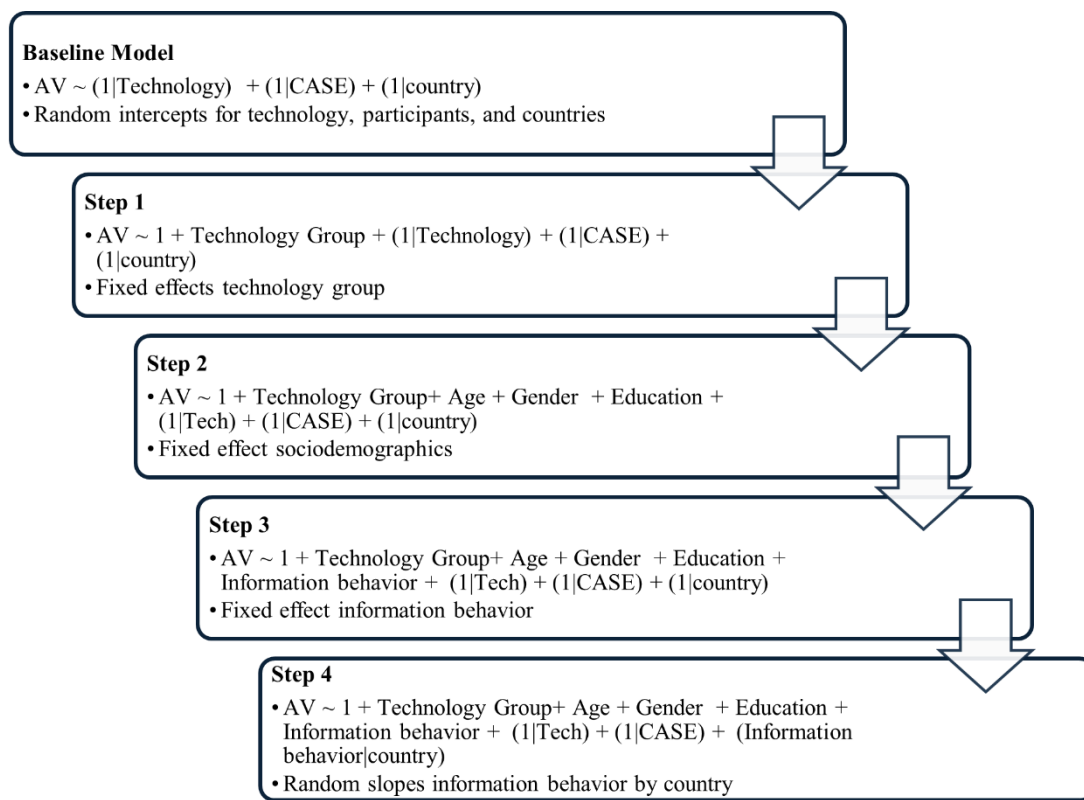
Furthermore, the third model was specified to examine the influence of information behavior on subjective knowledge and subjective relevance perception (*RQ1.3*), including technology group, person-level variables, and information behavior concerning emerging technologies as fixed effects on the individual level (see Figure 21, step 3). The final model for predicting the dependent variables specified technology group, person-level variables, and information behavior as fixed effects, along with information behavior modeled with random slopes by country (see Figure 21, step 4) accounting for the possibility that the relationship between information behavior and subjective knowledge or subjective relevance perception could differ across countries (*RQ1.4*). As in previous models, technology stimuli and participants were included as random effects. To determine whether the extensive model with random slopes of information behavior by country provided a better fit to the data than the model with random intercepts and fixed slopes, likelihood-ratio tests were done. Comparing the random-intercepts model to a model with random slopes for information behavior by country showed no improvement in model fit, $\chi^2(20) = 16.23, p = .70$. The model with slopes had a deviance of 5370.4 (compared to 5386.6 without slopes) and a slightly higher AIC (5444.4 compared to 5420.6), indicating that adding random slopes did not improve model fit.

A similar outcome was observed in the model predicting subjective personal relevance perception, where the model including random slopes for information behavior by country did not improve model fit compared to the model with random intercepts only. As such, the likelihood-ratio test indicated no significant improvement, $\chi^2(27) = 22.14, p = .73$. The model with slopes had a deviance of 4916.2 compared to 4938.3 without slopes, and a slightly higher AIC (5006.2 and 4974.3). This was also the case for the random slopes model predicting societal relevance perception. The likelihood-ratio test indicated no significant improvement of model fit, $\chi^2(27) = 1.30, p = 1$. The model with random slopes had a slightly lower deviance (4880.3) and a slightly higher AIC (4970.3) compared to the model with fixed slopes.

Due to the results of the likelihood-ratio tests, the decision was made to report the final results from the model with fixed slopes. In addition, it was imperative to assess the statistical assumptions of the mixed models. Random effects residuals were expected to follow a normal distribution, as assessed via Q–Q plots. This condition was generally met

for all models, with only minor deviations. Because the method has been considered robust, these deviations are unlikely to have a significant impact (Raudenbush & Bryk, 2002). Multicollinearity of the predictors was assessed using variance inflation factor (VIF) values. Since all predictors had low VIFs (< 10), no multicollinearity was present, and coefficient stability and interpretability were not affected (J. Cohen et al., 2003).

Figure 21. Data analysis plan study 1 for the mixed effects data structure with stepwise inclusion of fixed effects



5.3 Results

In the following sections, the results of the first empirical study are presented with respect to the influence of person-level, topic-level, and country-level differences (5.3.1). Subsequently, an overview is provided on the evaluation of emerging technologies concerning the dependent variables of subjective knowledge and subjective relevance perception (5.3.2). Furthermore, the results pertaining to the impact of respondents' information behavior and their country of origin on technology evaluation will be presented (5.3.3).

5.3.1 The Influence of Person-level, Topic-level, or Country-level differences

In regard to *RQ1.1*, three intercept-only models were specified without fixed effects, including solely random intercepts for participants, countries, and technology stimuli to predict the outcome variables of subjective knowledge, subjective personal relevance perception, and subjective societal relevance perception of emerging technologies.

For the first model predicting subjective knowledge, the total variance was 3.27, which was split as follows: 40.5% of the variance was between participants, 10.7% between countries, and 14.5% between technology stimuli (see Table 7). This left 34.4% of the variance unexplained, meaning it could not be attributed to participants, countries, or technology stimuli. These ICC values suggested a moderate level of agreement among individuals regarding their subjective knowledge, while the variability attributable to technology and country levels was minimal.

Regarding the perception of personal relevance of emerging technologies, the total variance was 3.28. In addition, the ICC for personal relevance perception at the person level indicated a moderate level of agreement, with 41.8% of the variance explained by individual differences. However, the variability attributable to technology stimuli was low, explaining only 7% of the variance, while 14.6% of the variance could be attributed to differences between countries (see Table 7). Furthermore, the model predicting the perception of societal relevance exhibited a total variance of 2.88, with 43.8% of the variance attributed to differences between individuals. In contrast, the variability attributable to both countries (10.1%) and technology stimuli (8%) was comparatively negligible (see Table 7). A residual 38.2% of the variance remained unexplained. In conclusion, addressing *RQ1.1*, the person-level variance was the largest across all models, indicating that individual differences play a more significant role in shaping subjective knowledge and subjective relevance perception toward emerging technologies compared to country or technology factors.

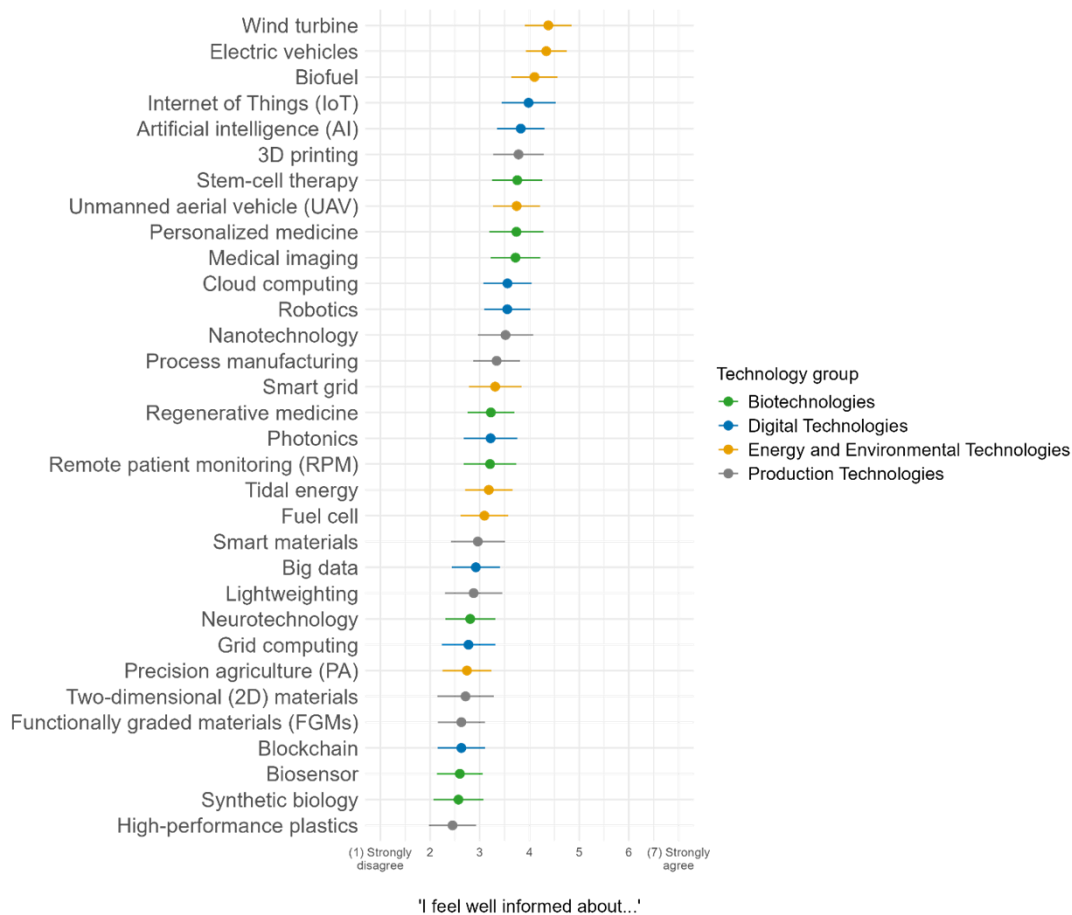
5.3.2 Overview on the Evaluation of the Technology Issues

As the research objective of the study encompassed the identification of discrepancies between technology issues with regard to their assessment by respondents, the initial approach was to obtain a descriptive overview of the technology issues by investigating the differences in mean scores in ratings of the dependent variables. These mean scores were calculated and arranged between the 32 technologies used in the newspaper stimuli according to the values of the scales used that ranged for subjective knowledge, as well as

5. Study 1: Influence of Contextual and Individual Determinants

subjective relevance perception (concerning subjective personal relevance and subjective societal relevance perception) from 1 to 7 point-scales (see [online appendix](#) for mean scores and standard deviations of the dependent variables for all 32 technologies investigated). As Figure 22 shows, *energy and environmental technologies*, such as wind turbine ($M = 4.38$, $SD = 1.79$) and electric vehicles ($M = 4.33$, $SD = 1.57$), were regarded as technologies in which participants considered themselves to be the most knowledgeable. Conversely, high performance plastics ($M = 2.45$, $SD = 1.71$) and synthetic biology ($M = 2.57$, $SD = 1.74$) were positioned at the lower end of the subjective knowledge spectrum, as respondents indicated a lower level of familiarity with these domains.

Figure 22. Mean scores of subjective knowledge of emerging technologies and technology groups

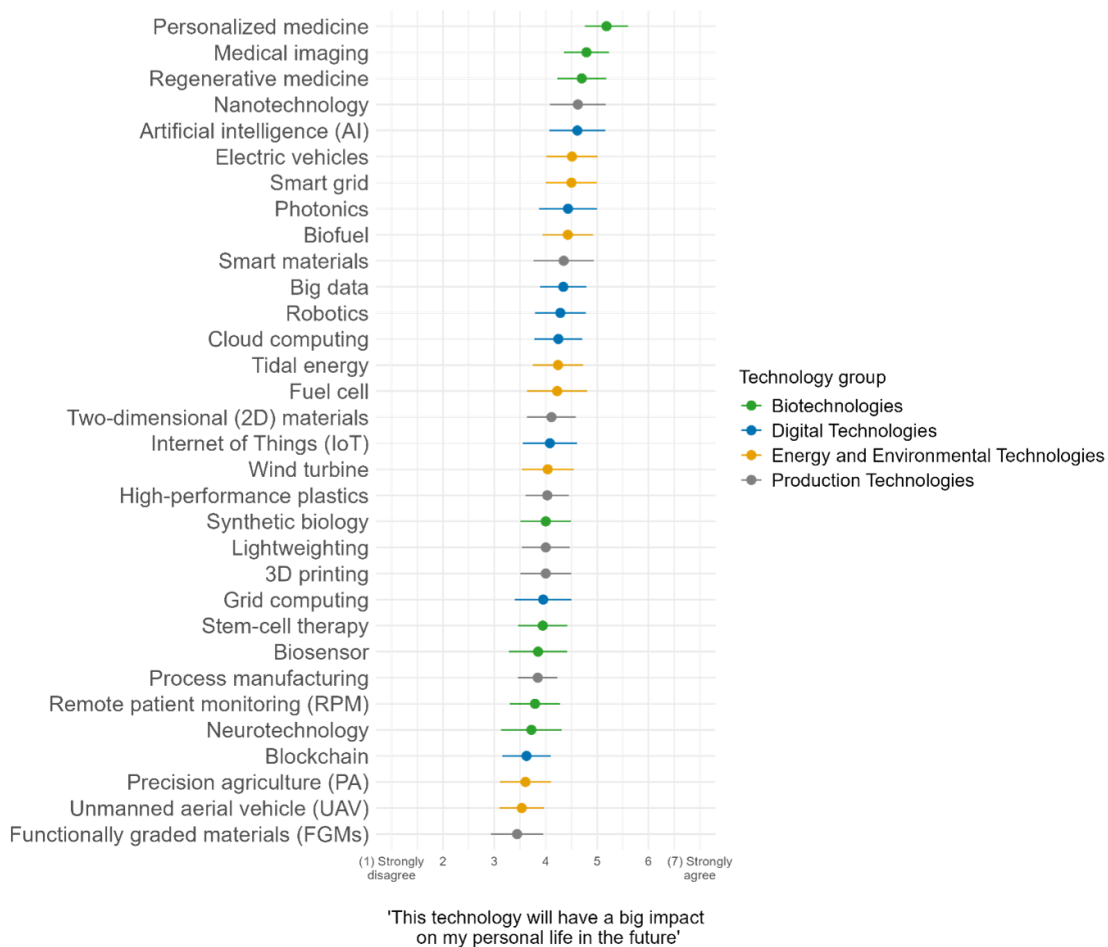


$n = 501$, points denote average subjective knowledge scores per technology and technology groups (scale: 1 = strongly disagree; 7 = strongly agree). The values for subjective knowledge were estimated for 95% CI.

In the context of the dependent variable of *subjective personal relevance*

perception, Figure 23 shows that especially *biotechnologies*, such as personalized medicine ($M = 5.18, SD = 1.58$) and medical imaging ($M = 4.79, SD = 1.64$) were considered as the most important technologies while functionally graded materials (FGMs) ($M = 3.44, SD = 1.85$) and unmanned aerial vehicle (UAV) ($M = 3.53, SD = 1.58$) received the lowest ratings.

Figure 23. Mean scores of subjective personal relevance perception of emerging technologies and technology groups

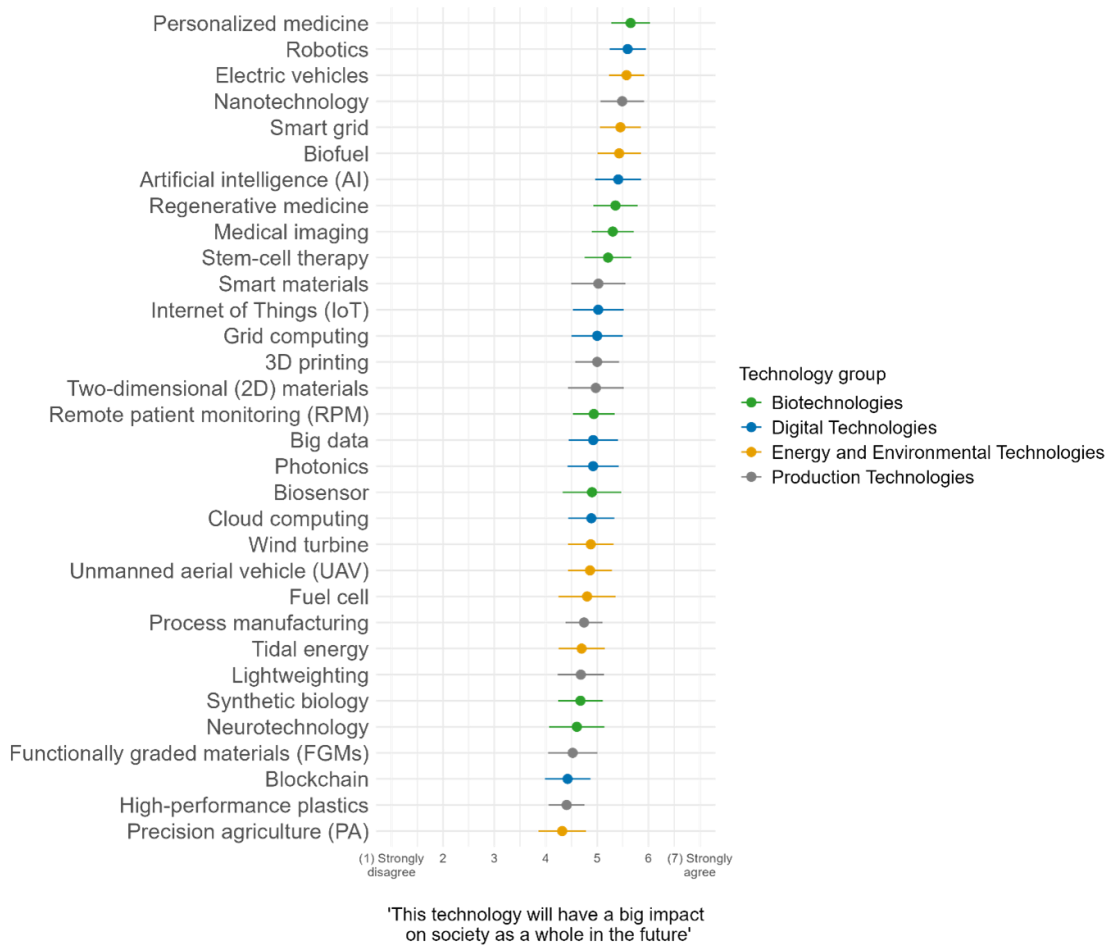


$n = 461$, points denote average subjective personal relevance perception scores per technology and technology groups (scale: 1 = strongly disagree; 7 = strongly agree). The values for subjective personal relevance perception were estimated for 95% CI.

For *subjective societal relevance perception*, as indicated in Figure 24, participants evaluated personalized medicine ($M = 5.65, SD = 1.42$) and robotics ($M = 5.59, SD = 1.31$) as having the greatest impact, and precision agriculture ($M = 4.31, SD = 1.83$)

and high-performance plastics ($M = 4.40$, $SD = 1.26$) were rated as having the least impact on society.

Figure 24. Mean scores of subjective societal relevance perception of emerging technologies and technology groups

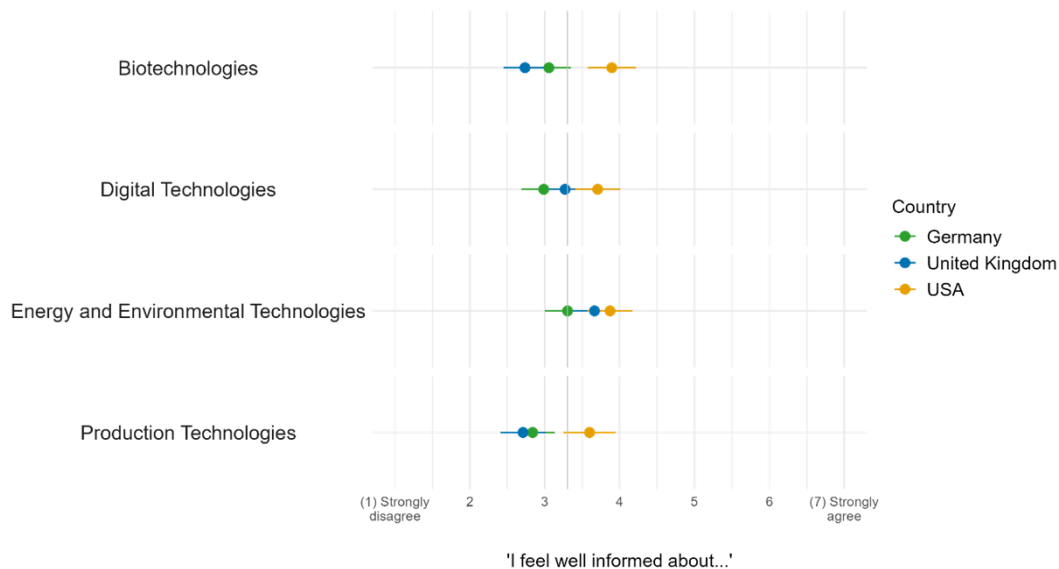


$n = 466$, points denote average subjective societal relevance perception scores per technology and technology groups (scale: 1 = strongly disagree; 7 = strongly agree). The values for subjective societal relevance perception were estimated for 95% CI.

Furthermore, the study investigated the differences in outcome variables across the three sample countries. As revealed by Figure 25, a clear pattern emerged for the reported levels of *subjective knowledge* regarding the various technology types in the sample countries. For instance, in the case of *biotechnologies*, US respondents showed a mean score of $M = 3.90$ ($SD = 1.96$), which surpassed the scores of German respondents ($M = 3.06$, $SD = 1.79$) and British respondents ($M = 2.74$, $SD = 1.74$). This score also exceeded the grand mean for biotechnologies, which was $M = 3.23$ ($SD = 1.89$). A similar

trend was observed for *digital technologies*, where US respondents reported the highest level of subjective knowledge ($M = 3.71$, $SD = 1.84$), followed by British respondents ($M = 3.27$, $SD = 1.96$) and German respondents ($M = 2.99$, $SD = 1.84$). The overall mean for these technologies was $M = 3.23$ ($SD = 1.90$). Regarding *energy and environmental technologies*, this category achieved the highest mean score among all technology groups ($M = 3.61$, $SD = 1.88$). US respondents reported a higher knowledge level in this area ($M = 3.87$, $SD = 1.85$) than both British ($M = 3.66$, $SD = 1.85$) and German respondents ($M = 3.30$, $SD = 1.90$). In the case of *production technologies*, which demonstrated the lowest overall knowledge level ($M = 3.05$, $SD = 1.98$), US respondents once again exhibited higher knowledge ($M = 3.60$, $SD = 2.14$) in comparison to German respondents ($M = 2.84$, $SD = 1.79$) and British respondents ($M = 2.71$, $SD = 1.88$). In summary, the findings indicate that US respondents generally perceive themselves as more knowledgeable about emerging technologies than their counterparts in the United Kingdom and Germany across all technology groups studied.

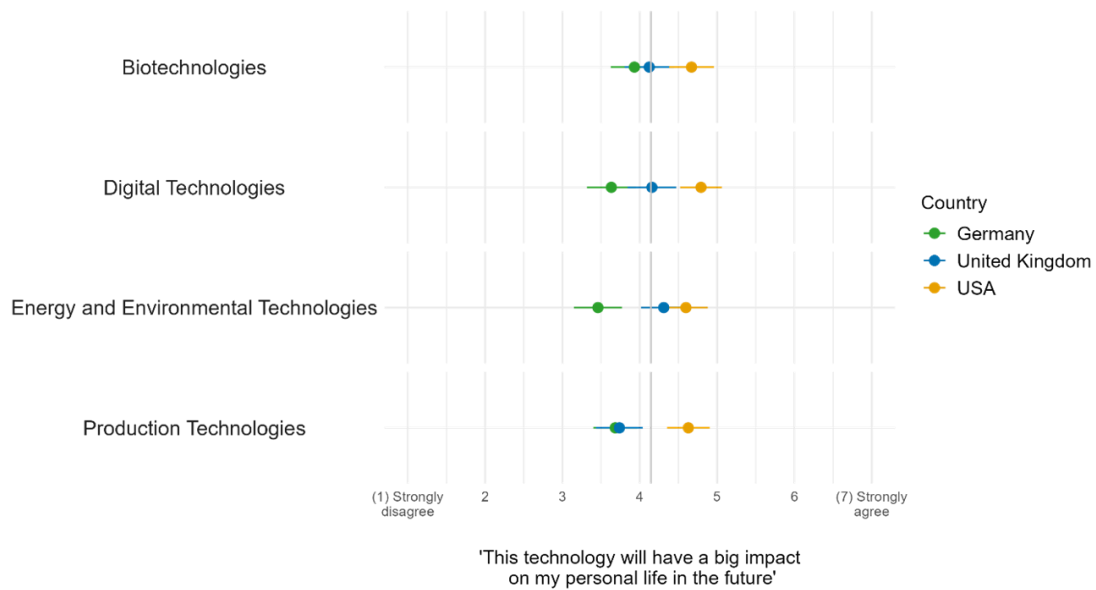
Figure 25. Mean scores of subjective knowledge of emerging technologies for technology groups and investigated countries



$n = 501$, points denote average subjective knowledge scores per technology group and country (scale: 1 = strongly disagree; 7 = strongly agree). Lines refer to the grand mean by technology group. The values for subjective knowledge were estimated for 95% CI.

The analysis of *subjective personal relevance perception* regarding emerging technologies shows distinct patterns across different technology groups, highlighting the varying views among respondents from the United States, the United Kingdom, and Germany which is shown in Figure 26, *biotechnologies* were identified as the technology group with the highest personal relevance ($M = 4.26$, $SD = 1.87$). Respondents from the United States demonstrated a notably higher mean relevance score of $M = 4.67$ ($SD = 1.75$), suggesting a pronounced perception of its personal significance. In comparison, respondents from the United Kingdom assigned a lower mean relevance score of $M = 4.12$ ($SD = 1.94$), showing a more moderate view of biotechnologies' significance. German respondents exhibited the lowest subjective personal relevance for this technology group, with a mean score of $M = 3.93$ ($SD = 1.86$). For *digital technologies*, the United States again led with a high mean relevance score ($M = 4.79$, $SD = 1.66$), while the United Kingdom followed ($M = 4.16$, $SD = 1.93$). In Germany, the mean relevance for digital technologies was the lowest ($M = 3.63$, $SD = 1.95$). This trend suggests that while digital technologies are recognized as relevant across all countries ($M = 4.21$, $SD = 1.90$), the perceived significance is particularly high among US respondents. A similar pattern was observed in the case of *energy and environmental technologies*, where US respondents again exhibited the highest mean score of $M = 4.60$ ($SD = 1.75$), suggesting a notable personal relevance. In contrast, the United Kingdom demonstrated a mean relevance score of $M = 4.31$ ($SD = 1.87$), while German respondents assigned the lowest relevance score in this group at $M = 3.46$ ($SD = 1.93$). Finally, for *production technologies*, which were considered as the least personally relevant type of technologies ($M = 4.04$, $SD = 1.82$), the United States again reported the highest mean relevance score of $M = 4.63$ ($SD = 1.69$), while the United Kingdom ($M = 3.74$, $SD = 1.91$) and Germany ($M = 3.68$, $SD = 1.71$), demonstrated a lower yet still moderate level of relevance perception.

Figure 26. Mean scores of subjective personal relevance perception of emerging technologies for technology groups and investigated countries

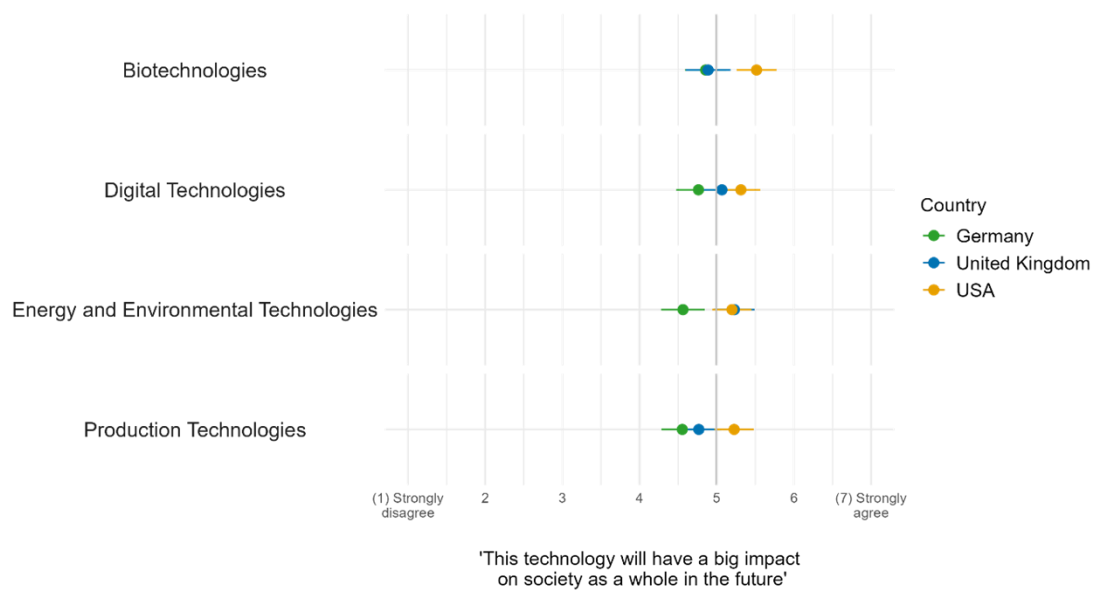


$n = 461$, points denote average subjective personal relevance perception scores per technology group and country (scale: 1 = strongly disagree; 7 = strongly agree). Lines refer to the grand mean by technology group. The values for subjective personal relevance perception were estimated for 95% CI.

The analysis of *subjective societal relevance perception* of emerging technologies again exhibits differences among various technology groups across the three investigated countries, as demonstrated in Figure 27. *Biotechnologies* were regarded as the most relevant group of technologies for society ($M = 5.10$, $SD = 1.68$). Moreover, respondents from the United States reported a mean societal relevance score of $M = 5.52$ ($SD = 1.57$), which was notably higher than the scores from the United Kingdom ($M = 4.89$, $SD = 1.76$) and Germany ($M = 4.86$, $SD = 1.63$). In regard to *digital technologies* ($M = 5.06$, $SD = 1.71$), the US once again demonstrated the highest mean score of $M = 5.31$ ($SD = 1.54$), followed by the UK with $M = 5.07$ ($SD = 1.79$) and Germany with $M = 4.76$ ($SD = 1.77$). For *energy and environmental technologies* ($M = 5.01$, $SD = 1.69$), US respondents scored the highest at subjective societal relevance ($M = 5.20$, $SD = 1.57$), while UK respondents rated these technologies lower ($M = 5.23$, $SD = 1.68$), as well as German respondents ($M = 4.56$, $SD = 1.76$). In the category of *production technologies* ($M = 4.86$, $SD = 1.69$), US respondents exhibited higher ratings of societal relevance ($M = 5.22$, $SD = 1.56$) compared to UK respondents ($M = 4.77$, $SD = 1.80$) and German respondents ($M = 4.55$, $SD = 1.63$). Therefore, respondents from the United States consistently assigned

a higher level of relevance to technologies across all technology groups than did respondents from the United Kingdom and Germany. Biotechnologies and digital technologies received particularly high ratings in the United States, with respondents perceiving these technologies as highly relevant to societal challenges. In contrast, respondents from the United Kingdom and Germany tended to view these technologies as comparably impactful, albeit to a lesser extent.

Figure 27. Mean scores of subjective societal relevance perception of emerging technologies for technology groups and investigated countries



$n = 466$, points denote average subjective societal relevance perception scores per technology group and country (scale: 1 = strongly disagree; 7 = strongly agree). Lines refer to the grand mean by technology group. The values for subjective societal relevance perception were estimated for 95% CI.

5.3.3 Information Behavior as Determinant and the Influence of Country Background

In order to achieve a more nuanced understanding of the variance between the factors of technology, groups, sociodemographic factors, information behavior, and country background, a series of mixed models were conducted for analysis⁵⁶. According to *RQ1.2*,

⁵⁶ For the detailed results of the step-wise procedure of the mixed models as described in chapter 5.2.5 see [online appendix](#).

which pertained to the evaluation of the influence of the technology groups in the newspaper articles, a mixed model incorporating technology groups as a fixed effect was utilized. This initial model explained 1% of the variance through fixed effects (marginal $R^2 = 0.01$), while the total variance explained, including random effects (person, technology, and country), was 62% (conditional $R^2 = 0.62$). However, no significant differences were found in how specific types of technology predicted subjective knowledge. This finding indicates that, while technology is a contributing factor, it may not be the predominant source of individual differences in subjective knowledge.

Another mixed model incorporated *sociodemographic variables* (age, gender, education) alongside technology groups as fixed effects. In this model, the fixed effects explained 6% of the variance (marginal $R^2 = 0.06$), representing a 5% increase in explained variance due to the inclusion of personal characteristics. The conditional R^2 remained the same at 62%, indicating that the random effects continued to account for the majority of the variance. Importantly, the analysis revealed significant contributions from sociodemographic factors. First, with the factor of age ($b = -0.02, p < .001$), indicating that older individuals reported lower levels of subjective knowledge. Moreover, female respondents indicated lower levels of subjective knowledge compared to male respondents ($b = -0.37, p = .007$). And higher education at the university level was significantly associated with greater subjective knowledge ($b = 0.50, p = .004$). These results suggest that while personal characteristics such as age, gender, and education significantly enhance the model's explanatory power at the individual level, random effects such as person level differences, technology stimuli and countries still explain the majority of the variance in subjective knowledge.

To detect the influence of respondents' *information behavior* on subjective knowledge of emerging technologies, a mixed model was specified to answer *RQ1.3*, with respondents' information behavior as an additional fixed effect. This step resulted in a significant increase in explanatory power, with fixed effects now accounting for 61% of the variance in subjective knowledge (marginal $R^2 = 0.61$). The total variance explained by the third model increased to 75% (conditional $R^2 = 0.75$). This indicates that while socio-demographic factors significantly improved the explanatory power of the model, the inclusion of information sources substantially added to the understanding of subjective knowledge. In what follows, results from the mixed models incorporating the use of information sources are reported. As indicated in Table 9, Model 1, the use of *television* for technology-related news was significantly and positively associated with subjective

knowledge ($b = 0.13, p < .001$). In addition, the use of *print news* ($b = 0.14, p < .001$), *interpersonal communication with family and friends* ($b = 0.15, p < .001$), and *conversation with experts* ($b = 0.07, p = .011$) were also significant positive predictors of subjective knowledge. However, the strongest positive association with subjective knowledge was found for the use of *online sources* ($b = 0.34, p < .001$). In terms of sociodemographic variables, *high school education* ($b = 0.26, p = .007$) and *university education* ($b = 0.32, p = .001$) were positively related to subjective knowledge.

Two additional models were estimated to investigate how *subjective personal relevance perception* and *subjective societal relevance perception* are predicted by the technology groups, sociodemographic factors, information behavior and subjective knowledge. Concerning *subjective personal relevance perception*, overall, the explained variance was 65%, with 30% variance attributable to fixed effects. As shown in Table 9 Model 2, subjective knowledge ($b = 0.14, p < .001$) was a positive predictor of subjective personal relevance. Besides, a *higher education level* (university) was positively related to subjective personal relevance ($b = 0.33, p = .031$). Among the information behavior variables, only the use of *online media* ($b = 0.20, p < .001$) and *consulting experts* ($b = 0.12, p < .001$) significantly affect the perception of subjective personal relevance.

For *subjective societal relevance perception*, 64% of the variance was explained by the model. Moreover, 21 % in the variance was explained by the fixed effects in the model. Table 9 (Model 3) indicates that individuals who consider themselves more knowledgeable about emerging technologies experience higher subjective societal relevance ($b = 0.18, p < .001$). There was also a significant negative relationship between production technologies and subjective societal relevance ($b = -0.21, p = .024$), suggesting that *production technologies* were perceived as less personally socially relevant than biotechnologies (used as baseline). Significant positive relationships emerged for respondents' *age* ($b = 0.00, p = .033$), *high school education* ($b = 0.34, p = .021$), and *university education* ($b = 0.49, p = .001$) in explaining subjective societal relevance perception regarding emerging technologies. Regarding information sources, the use of *television* ($b = 0.08, p = .017$), *print media* ($b = -0.08, p = .020$), and *online sources* ($b = 0.12, p < .001$) as well as *discussions with friends and family* ($b = 0.11, p < .001$) for technology information, significantly predicted subjective societal relevance perception.

In answering *RQ1.3*, the analysis revealed that information behavior significantly influenced subjective knowledge, personal relevance, and societal relevance. Of the information sources investigated, online media use was the strongest predictor of

subjective knowledge and perceptions of personal and societal relevance of emerging technologies. Moreover, the results suggest that increasing individuals' knowledge of these technologies can positively influence how relevant and important audiences perceive them to be, both in their personal lives and in society at large.

Furthermore, *RQ1.4* asked whether there are *cross-country differences* in the effect of sources of information on subjective knowledge and perceptions of relevance with respect to emerging technologies. To address this, it was tested whether the *random slopes* differed significantly across countries. If the random slopes are significant, it means that the strength of the relationship between information sources and outcomes differs across countries. As shown in section 5.2.5, model fit comparisons indicated that including random slopes for information behavior across countries did not improve model fit, so the final models (see Table 9) only reported results based on the random intercept models with fixed slopes. Evaluating the models with random slopes for information behavior by country for the three outcome variables confirmed this negligible impact of cross-country differences. For subjective knowledge, the variances of the random slopes for television use, peer communication, and expert communication were 0.00, indicating no cross-country variability. Print news and online sources had low variability with variances of 0.01 each, suggesting very small differences in how these sources affect subjective knowledge across countries. For subjective personal relevance, the random slopes for television, print news, online news, peer communication, and expert communication all had variances of 0.00, indicating no cross-country differences in the effect of these sources of information. In contrast, for societal relevance, there were very small cross-country differences in the effects of peer and expert communication, each with a random slope variance of 0.01.

Therefore, regarding *RQ1.4*, it was found that there were minimal cross-country differences in the effect of information sources on subjective knowledge and perceptions of relevance regarding emerging technologies, with only minor variability in subjective knowledge for print and television news, and also minor variability in societal personal relevance for peer and expert communication.

Table 9. Results of the linear mixed-effect models predicting subjective knowledge, subjective personal relevance perception and subjective societal relevance perception concerning emerging technologies

	Model 1		Model 2		Model 3	
	<i>b</i>	95% <i>CI</i>	<i>b</i>	95% <i>CI</i>	<i>b</i>	95% <i>CI</i>
Fixed effects						
Digital technologies	-0.01	-0.25 – 0.23	-0.03	-0.25 – 0.19	-0.06	0.13 – 0.24
Energy and environmental technologies	0.16	-0.09 – 0.40	-0.20	-0.43 – 0.02	-0.18	-0.24 – 0.12
Production technologies	-0.13	-0.37 – 0.11	-0.19	-0.42 – 0.03	-0.21*	-0.36 – 0.00
Age	-0.00	-0.01 – 0.00	-0.00	-0.01 – 0.00	0.00*	-0.39 – -0.03
Gender female	-0.07	-0.22 – 0.08	-0.02	-0.26 – 0.21	0.23	0.00 – 0.02
Education high school	0.26*	0.07 – 0.45	0.14	-0.15 – 0.43	0.34*	0.05 – 0.63
Education university	0.32**	0.12 – 0.51	0.33*	0.03 – 0.62	0.49**	0.20 – 0.79
Television	0.13***	0.08 – 0.19	0.02	-0.05 – 0.09	0.08*	0.01 – 0.14
Print news	0.14**	0.09 – 0.20	0.03	-0.05 – 0.10	-0.08*	-0.14 – -0.01
Online news	0.34***	0.29 – 0.39	0.20***	0.13 – 0.27	0.12***	0.05 – 0.18
Peer group	0.15***	0.10 – 0.21	0.07	0.00 – 0.14	0.11***	0.05 – 0.18
Experts	0.07*	0.02 – 0.12	0.12***	0.05 – 0.19	0.03	-0.03 – 0.09
Subjective knowledge			0.14***	0.07 – 0.20	0.18***	0.13 – 0.24

N = 501 participants, *n* = 1,777 observations (Model 1), *n* = 461 participants, *n* = 1,429 observations (Model 2), *n* = 466 participants, *n* = 1,459 observations (Model 3). Non-standardized regression coefficients are reported. Reference groups for the categorical variables: digital technologies/energy and environmental technologies/production technologies = biotechnologies; gender female = gender male; education high school/ education university = education no schooling.

* $p < 0.05$; ** $p < 0.01$; ***, $p < 0.001$

5.4 Summary and Discussion

This study provided important insights into the factors influencing individuals' *subjective knowledge, subjective personal relevance perception, and subjective societal relevance perception* of emerging technologies across a participant sample from the United States, United Kingdom, and Germany ($N = 501$).

Person-level, technology-level, and country-level differences

Overall, the findings of study 1 underscore the considerable influence of individual differences on perceptions of emerging technologies at the individual level, while country- and technology-level effects appear to have a comparatively smaller impact. These findings suggest that personal characteristics — such as media use, education, age, and gender — play a dominant role in how media recipients perceive and engage with emerging technologies. Accordingly, the present findings align with prior research in the domain of technology adoption and public understanding of science, which has repeatedly demonstrated that personal factors, including cognitive ability, education, and attitudes toward science, exert a substantial influence on individuals' engagement with technological advancements (Brossard & Nisbet, 2007; Ho et al., 2008; Nisbet et al., 2002).

Evaluation of technology types

This study further provided insights into the subjective knowledge and subjective relevance perception of 32 emerging technologies, highlighting minor variations across technology types. Moreover, the findings indicated that the respondents' levels of subjective knowledge demonstrated minimal variability across various technology domains. In addition, this showed the varied ways in which different types of technologies are perceived across the three countries. For instance, the participants exhibited a higher level of subjective knowledge regarding energy technologies, such as wind turbines and electric vehicles, in comparison to biotechnologies or production technologies. Hence, it can be deduced that certain technologies are more familiar and accessible to the participants. This finding aligns with the notion that more established or highly publicized technologies, such as renewable energy solutions, may enjoy greater public awareness (Huijts et al., 2012), while emerging or specialized fields like synthetic biology (D. A. Scheufele & Lewenstein, 2005) remain less understood in the public.

Overall, biotechnologies and digital technologies were regarded as the most subjective relevant technology fields across all three nations. This phenomenon may be

attributed to their tangible and direct influence on health, lifestyle, and societal challenges, including environmental sustainability and healthcare (Ciarli et al., 2021; Lokko et al., 2018). In the context of biotechnologies, it is plausible that they are perceived as more pertinent than other technology groups, a circumstance that can be attributed to media framing and the issue-attention cycles, particularly during the period of heightened focus on biotechnologies that coincided with the COVID-19 pandemic (Mheidly & Fares, 2020; Rauchfleisch et al., 2021). Conversely, production technologies, such as functionally graded materials, were considered less relevant. This may be indicative of their less direct impact on daily life or their perception as innovations specific to industry (Bai et al., 2020; Daamen et al., 1990).

In accordance with the findings of Allum et al. (2008), there was minimal variability in the subjective knowledge and subjective relevance perception of emerging technologies observed across different nations. However, the respondents from the US sample reported higher levels of subjective knowledge and subjective relevance perception for all technology groups compared to the respondents from the German or British sample. While differences in media coverage and framing across countries may be a factor, the comparability of the greater economic impact of technologies in the United States may better explain these differences (NSF, 2022). The United States economy has a substantial technological footprint, marked by elevated levels of investment in research and development (R&D) and the presence of prominent technology companies such as Google, Apple, and Amazon (National Science Board, 2018). These factors may contribute to a perception of technology as a primary catalyst for economic growth, job creation, and global competitiveness.

The role of sociodemographic factors and information behavior

Taking into account sociodemographic factors such as age, gender, and education level alongside information behavior yielded a more nuanced understanding of how individuals develop their perceptions of emerging technologies. These findings indicated that education emerged as a reliable predictor of subjective knowledge and its perceived relevance. Individuals with a university education exhibited a heightened sense of subjective knowledge and regarded emerging technologies as more relevant. As shown by the findings of prior studies, higher educational attainment has been demonstrated to be associated with increased technological literacy and interest (Drummond & Fischhoff, 2017; Hoekstra et al., 2024).

Moreover, information behavior emerged as a critical factor in shaping technology perceptions. In line with comparable findings, the use of online sources, print media, television, and interpersonal communication with friends, family, and experts were positively associated with higher subjective knowledge (Nisbet et al., 2002). Online news, in particular, showed the strongest positive association, which reflects the growing importance of digital information channels in disseminating knowledge (Davies & Hara, 2017). As for example discussed by Brossard and Nisbet (2007), this suggests an indirect impact of news media sources as an informal source of learning about science. By examining science user categories, further insights could be gained into the relationship between online science news consumption and subjective science knowledge. For instance, individuals who infrequently engage with science content may possess an inaccurate perception of their comprehension due to their limited exposure. In contrast, frequent users, particularly those driven by entertainment or routine, may develop an illusion of knowledge, leading them to overestimate their scientific understanding despite their limited empirical knowledge (Leonhard et al., 2020). Furthermore, it was evident that individuals who frequently utilized the internet were more inclined to express their support for fundamental scientific research (Brossard & Scheufele, 2013).

Limitations and implications

Overall, the results of study 1 confirmed the significant impact of media exposure on subjective knowledge regarding emerging technologies. Future research should explore whether media exposure facilitates discussions and influences knowledge gaps across socioeconomic groups (Tichenor et al., 1970). In contrast, subjective relevance perception had a weaker direct relationship with media use; however, online sources appeared to enhance subjective relevance perception. Further research is needed to understand how subjective relevance moderates the relationship between media use and attitudes toward science (Frewer et al., 1999). It is feasible that internet use leads to lower confidence in the mainstream press and a less favorable perception of scientists (Takahashi & Tandoc, 2016). However, another salient aspect pertains to the exploration of alternative online resources related to scientific disciplines. Such resources encompass science blogs and various social media channels. These additional online sources have the potential to influence one's comprehension of scientific concepts and moreover, they can facilitate recall and enjoyment through interactive mechanisms (Gardiner et al., 2018; Tang et al., 2021). Future studies should examine the implications of this apparent shift to the internet

for individuals seeking scientific information. Potential incentives for people interested in scientific developments may include the convenience and speed of accessing large amounts of information online. However, this could also be a symptom of a general distrust of traditional media as sources of information (Anderson et al., 2011).

In this study, cross-country differences in information behavior were negligible. Notwithstanding, researchers have not conducted many recent comparative studies evaluating technology perception and media use across diverse populations, particularly beyond the contexts of the European Union and Western regions. For instance, it was evident in Europe that northern countries (e.g., Britain, Denmark, France, and Germany) tend to have higher levels of public scientific knowledge than southern countries (Bauer et al., 1994).

Another limitation of the study is its reliance on self-reported data, which may be subject to biases such as the overestimation or underestimation of subjective knowledge (Rosenman et al., 2011). Subsequent research endeavors could integrate subjective assessments with empirical evaluations of technology knowledge, employing measures such as those utilized in the study of objective or “textbook knowledge” (see for example Rihn et al., 2021). While these knowledge variables are important indicators of how people engage with scientific information, recent research highlights that individual knowledge alone does not uniformly translate into more favorable attitudes toward science. Furthermore, an accumulating body of evidence suggests that individual differences, encompassing political identity, religious orientation, and ideological commitment, moderate the relationship between knowledge and attitudes (Anderson et al., 2014; Brossard & Nisbet, 2007; Nisbet & Markowitz, 2014). It is imperative that forthcoming studies examine an array of attitudinal variables, including support and acceptance, in regard to emerging technologies. This will facilitate a more profound understanding of these relationships and contribute to more understanding of how attitudes towards science and technology evolve.

Higher levels of general and science-specific education have been associated with increased technological literacy and interest (Bauer et al., 2007). However, these individuals are also linked to greater polarization on contested science topics. This pattern lends support to two complementary explanations. The first of these is the motivated reasoning account, which posits that individuals with greater knowledge employ their cognitive abilities to justify their preexisting beliefs (Druckman & Bolsen, 2011). Moreover, the miscalibration account proposes that individuals' confidence in their views tends to

increase more rapidly than their actual understanding (Drummond & Fischhoff, 2017). These additional insights underscore the importance of considering not only cognitive variables like knowledge but also motivational and affective factors that influence how scientific messages are received and evaluated.

Conclusion

In summary, the present study demonstrated that individual-level factors, particularly education and information-seeking behavior, are key determinants of how people perceive and engage with emerging technologies. While the technology type and the country of residence also play a role, their influence is relatively modest. In light of rapid technological change, the present findings underscore the importance of technology-specific strategies to foster informed and engaged publics. Consequently, a thorough investigation is imperative to ascertain the direct influences of media through news framing (Brossard & Nisbet, 2007). The subsequent chapter will extend these insights by empirically investigating the role of cognitive processes in media message reception, with a focus on attitude formation toward emerging technologies.

6. Study 2: Message Framing Effects

In order to detect differences in attitudes towards emerging technologies that originate from newspaper reporting, it is essential to employ experimental studies to ascertain causal relationships. As part of this investigation, an experimental study on message framing effects was conducted, with message manipulations in text and visuals to test effects on support and behavioral intentions towards emerging technologies. Study 2 is introduced in chapter 6.1, which sets out the research questions and hypotheses. Chapter 6.2 then explains the methods which were applied. Next, chapter 6.3 provides an overview of the results of the study, which are elaborated further in terms of implications in chapter 6.4.

6.1 Research Questions and Hypotheses

The influence of person-level and topic-level differences

Extensive discussion has taken place regarding the role of *individual characteristics* in variations in attitudes toward science and technology (Ho et al., 2010; Nisbet, 2005). People tend to process information differently depending on their motivation and cognitive resources. Often, they rely on simple cues and mental shortcuts, acting as "cognitive misers" to conserve effort (Taylor, 1981). However, when motivation and ability to process information are high, individuals may engage in more thoughtful and elaborate processing of arguments (Petty & Cacioppo, 1986a). In this context, valence framing, or how information is presented in positive or negative terms, can serve different functions depending on the likelihood of elaboration. When elaboration is low, message framing acts as a peripheral cue that influences judgments through simple associations. When elaboration is high, it serves as an agreement cue, shaping how individuals assess the strength and relevance of the arguments presented (Maheswaran & Meyers-Levy, 1990; Smith & Petty, 1996). However, the impact of individual or contextual differences in evaluating newspaper articles has not been extensively researched. Thus, it asked:

RQ2.1: Which factor contributes more to the explanation of support and behavioral intentions toward emerging technologies, differences at the level of persons or at the level of technology topics of newspaper stimuli?

Gain and loss message framing

Given the risky nature of emerging technologies and applications, media coverage relies on framing that often emphasizes both the risks and benefits of technologies (Cobb & Macoubrie, 2004). Previous research has examined the effects of valence framing which is goal-oriented in terms of how different, but logically equivalent, phrases influence individuals' attitudes and behavioral intentions (Chong & Druckman, 2007; Druckman, 2001a; Tversky & Kahneman, 1987). The effects of so-called "gain and loss framing" have been investigated in different contexts, including fear appeals on cigarette labels (Tannenbaum et al., 2015), disease prevention (Gantiva et al., 2021), and environmental policy (Lu, 2016). Furthermore, the overall effectiveness of gain and loss framing has been examined through meta-analyses, which have found small to moderate effect sizes, with the two framing modes having similar persuasive potential (Kühberger, 1998; O'Keefe & Jensen, 2006; O'Keefe & Jensen, 2007). However, it has been shown in a number of studies that gain framing is more influential than loss framing. For instance, Thacker et al. (2020) found that individuals exposed to messages emphasizing the benefits of genetically modified foods (GMFs) had significantly more favorable attitudes than those exposed to messages highlighting the related risks. Similarly, in the area of organ donation, gain-framed messages have been shown to elicit more favorable evaluations, stronger behavioral intentions, and lower levels of psychological reactance and perceived manipulative intent than loss-framed appeals (Reinhart et al., 2007). During the pandemic, messages that highlighted the benefits of preventive health behaviors were found to be more effective in motivating protective behaviors (Gantiva et al., 2021).

However, other studies found that loss framing was more influential than gain framing in influencing awareness and anxiety about disease prevention (Dorison et al., 2022; O'Keefe & Jensen, 2007). Fear appeals have been demonstrated to elicit positive changes in attitudes, intentions, and behaviors, especially when facilitated by fear and augmented by efficacy enhancing information (R. W. Rogers, 1983; Tannenbaum et al., 2015). Furthermore, uncivil user comments about nanotechnology have been shown to increase risk perceptions about the technology, while civil comments have not (Anderson et al., 2014). The reviewed studies show that the persuasiveness of gain and loss framing depends on the issue context; however, despite the reported findings, explicit research on goal framing effects emphasizing the gains and losses of emerging technologies lacks support. Thus, another research question asks about the effects of gain and loss text framing on the evaluation of emerging technologies:

RQ2.2: How does the valence of message framing (gain, loss, neutral) in newspaper articles influence participants' support for and behavioral intentions toward emerging technologies?

The visual presentation of message framing effects

How content is presented, such as through news articles, documentaries, or interactive graphics, also affects its effectiveness, as it can influence audience comprehension and engagement (Borah, 2009; Coleman, 2010). However, the majority of research on framing effects has examined textual framing effects without considering visual elements (Geise & Baden, 2015). Nevertheless, framing theory (Entman, 1993) can be applied to different modalities of communication, as these images are presented alongside news headlines that support different narratives. As noted in integrative framing approaches (e.g., Coleman, 2010; Geise & Baden, 2015), images viewed in isolation increase salience when combined with text. According to the "pictorial superiority effect" (D. L. Nelson et al., 1976), it has been argued that the framing properties of messages indicate different processing modes (Geise & Baden, 2015). Particularly for complex scientific findings, the use of graphics makes information easier to evaluate and more applicable to the reader (Trumbo, 1999), increases perceived message effectiveness (Tal & Wansink, 2016), and can lead to a higher degree of message elaboration, for example within the context of risk assessment of events presented in the news (Gibson & Zillmann, 2000). For example, scientific beliefs that debunk the alleged link between autism and vaccines showed to be reinforced when presented with images of scientists (Dixon et al., 2015).

In an eye-tracking study, Dahmen (2012) found that photographs about the stem cell debate using medical, scientific, and ethical framing influenced visual attention but did not change attitudes about the issue. Regarding the combination of textual framing and visuals, Bingaman et al. (2021) demonstrated that support for the issue of artificial intelligence was highest when a social progress frame was paired with benign images and lowest when a Pandora's box frame was paired with threatening visuals. Similarly, Powell et al. (2015) showed that obligation-framed images increased support and behavioral intentions more than risk-framed images, with images influencing behavior more than text, particularly through emotional responses. The effect of loss-framed messages on recycling behavior, which was reinforced by infographics, was evidenced by a study by G. Huang et al. (2019), in which perceived harm to respondents or other individuals was elevated. Overall, supporting valence text framing with images as a visual cue is expected

to enhance elaboration and thus positively impact attitude formation, although empirical evidence for emerging technologies is sparse. The following research question is posed:

RQ2.3: How does the valence of the accompanying picture (positive, negative, no image) in newspaper articles affect participants' support for and behavioral intentions toward emerging technologies?

Message congruency in text framing and visual presentation

Research on text-visual alignment, or its "message matching," has emphasized the importance of congruency in persuasive communication (see also chapter 4.2.2). When message content is congruent with the basis of the attitude and recipients are motivated to process information deeply or under high elaboration likelihood, persuasive outcomes are more favorable (Chaiken & Maheswaran, 1994; Lavine & Snyder, 1996). Regarding message congruency, it is imperative to examine whether the alignment of message framing, such as the valence of newspaper text and the accompanying images of the same or different valence, generates disparate effects. The use of congruent messages, combining text and pictures, has been demonstrated to be more effective in general. A substantial body of research has demonstrated the efficacy of such messages in enhancing memory processes, influencing attitudinal outcomes, and encouraging specific behavioral intentions (J. Lee & Cho, 2022; Powell et al., 2015; Seo & Dillard, 2019).

Accordingly, gain framing that is presented in alignment with a positive image has been demonstrated to require less cognitive processing effort and has been associated with more favorable evaluations of an issue than non-congruent conditions of gain framing and negative imagery (J. Lee & Cho, 2022; Seo & Dillard, 2019). In summary, positive valence in pictures that is congruent with the text is expected to enhance the overall message framing effects. Therefore, the initial hypothesis of study 2 posits that when visual elements align in a positive valence within gain framing in the text, the message will foster more favorable attitudes toward the issue of emerging technologies compared to conditions in which this is not the case:

H2.1: A gain-framed message paired with a picture of positive valence will significantly increase support and behavioral intentions toward a technology more than a neutral framing message paired with no picture.

H2.2: A gain-framed message paired with a picture of positive valence will significantly increase support and behavioral intentions toward a technology more than a gain-framed message paired with a picture of negative valence.

In accordance with the studies on message valence congruency that have been reviewed, congruent pairings of text- and picture-based messages generally resulted in more pronounced persuasive effects, particularly in gain-framed conditions. However, in certain loss-framed scenarios, congruent pairings exhibited superior persuasiveness in comparison to congruent pairings of positive valence. As demonstrated in the research, fear appeals—which combine loss-framed text with unpleasant images—are an effective strategy to amplify the intention to quit smoking (Zhao et al., 2014) or to elicit a heightened sense of fear in respondents (Seo et al., 2013). In contrast, the use of mismatched messages—that is, the presentation of a loss-framed message alongside a positive image—proved to be less effective. These messages were for example observed to elicit negative emotions or cognitive resistance among participants (Seo & Dillard, 2019). Therefore, the next pair of hypotheses of this study are postulated as follows:

H2.3: A loss-framed message paired with a picture of negative valence will significantly increase support and behavioral intentions toward a technology more than a neutral framing message paired with no picture.

H2.4: A loss-framed message paired with a picture of negative valence will significantly increase support and behavioral intentions toward a technology more than a loss-framed message paired with a picture of positive valence.

Moderators of congruency framing effects

Another relevant dimension in the interaction of messages on individuals' attitudes are participant characteristics, which include value predispositions, knowledge, elaboration, and emotional responses (see chapter 4.2.1 on the influence of these individual determinants). The persuasive effect of gain and loss framing has been shown to be influenced by how recipients reflect on and judge the content of a message, as the dominant cognitive response is shaped in the direction of the message (Seo & Dillard, 2019). A message's perceived effectiveness is related to how persuasive the message is in relation to the message's soundness; thus, a message's *perceived valence* (e.g., Yzer et al., 2015) provides

"favorable thoughts," which in turn influence attitudes (Dillard, Shen, & Vail, 2007). Previous research has shown that perceived message valence enhances the framing effects, when the image is congruent with the framed message (Dillard, Weber, & Vail, 2007; Seo & Dillard, 2019).

Several authors have highlighted the potential of respondent knowledge to enhance textual and visual framing effects for individuals with high topic-relevant knowledge (Powell et al., 2015; F. Shen, 2004). As discussed previously, topic-specific knowledge itself can be distinguished as either objective or subjective knowledge (see for example C.-Y. Park, 2001), but it could be argued that *subjective knowledge* is a stronger motivator of behavioral intentions due to direct experience with the topic (C. W. Park et al., 1994). Subjective knowledge of emerging technologies has been associated with support for them (Allum et al., 2008), as audiences gain general insight into emerging technologies primarily through media coverage rather than by retrieving specific textbook knowledge (C.-Y. Park, 2001).

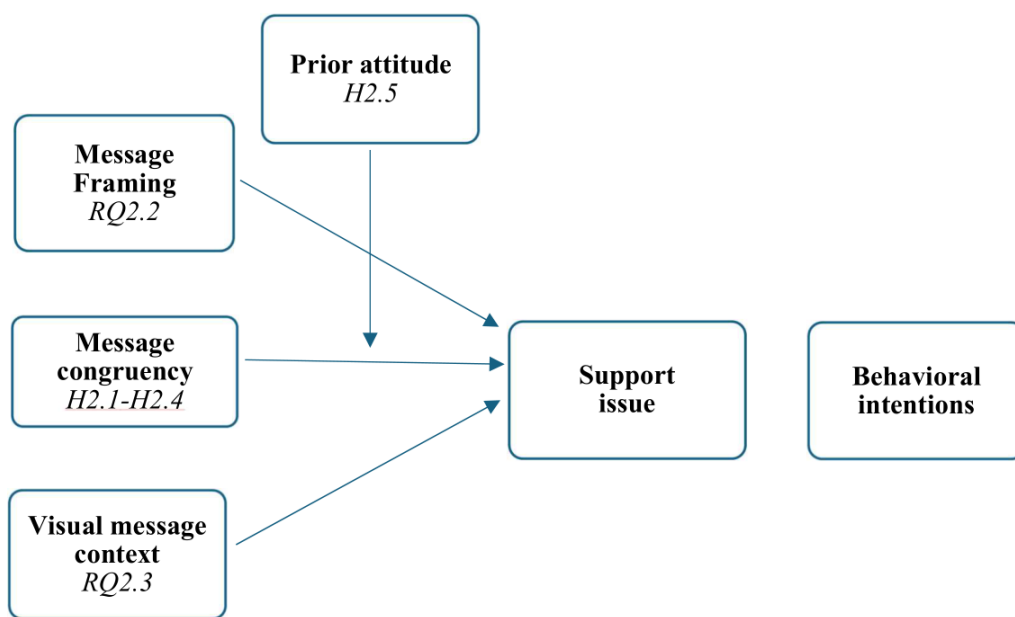
Consistent with persuasion theory, *the subjective personal relevance perception* of an issue may moderate the congruency effects of message framing because a high level of issue relevance activates more effort in the cognitive processing of the issue, which contributes to attitude change (Lavine & Snyder, 1996; Petty et al., 1981). Furthermore, the valence of the message framing is relevant in this regard, as negatively framed messages are more persuasive than positively framed messages when the recipients are highly motivated to process the messages (Maheswaran & Meyers-Levy, 1990). As shown in the context of green advertising, when the recipients have a low level of involvement and are reading non-congruent information compared to highly involved recipients, they showed more negative attitudes toward the product (J. Lee & Cho, 2022). Overall, these differences in each individual variable are expected to moderate the effect of congruency framing on attitudes toward emerging technologies:

H2.5: The effect of congruent message framing of text and visuals on support and behavioral intentions will be stronger for individuals with higher levels of perceived message valence, subjective knowledge, and subjective relevance perception.

Study 2 investigates the interplay between message congruency in media reporting about emerging technologies and its effect on recipients' attitudes. The first objective of this study is to research the influence of person-level and topic-level differences

(*RQ2.1*). Moreover, Figure 28 illustrates the anticipated effects of message framing valence (*RQ2.2*) and accompanying picture valence (*RQ2.3*) on attitudes. Then, differences between presentations of congruent or incongruent combinations of message valence and picture valence are examined in *H2.1* to *H2.4*. The impact of moderating variables, which are defined as the individual's prior attitudes, on the effect of message congruency on attitudes is also evaluated (*H2.5*).

Figure 28. Overview on determinants and outcomes regarding the research questions and hypotheses for study 2



6.2 Methods

The subsequent section delineates the methods employed in the second study, encompassing the experimental design and manipulation, procedural guidelines, measurement instruments, the sample population, and an overview of the data analysis procedure.

6.2.1 Experimental Design

As outlined in chapter 6.1, the proposed research questions and hypotheses for this study were formulated to examine the effects of message framing and picture valence on support and behavioral intentions toward emerging technologies, thereby proposing causal relationships between the variables. According to Shadish (2001), causal relationships exist when there is a relation between two or more variables, where alterations in one variable are associated with variations in another, and the cause variable precedes the effect variable in a sequential manner. Importantly, for true causality, no alternative explanations exist for the effect beyond those attributed to the cause. Thus, the experimental method mirrors causality by ensuring that the cause precedes the effect through manipulation, and the variation in the cause relates to variation in the effect (Shadish, 2001). In comparison to observational or correlational methods, experiments possess the capacity to address specific causal inquiries that are central to the research objectives. For instance, the experimental approach can elucidate the influence of different types of media messages on technology attitudes.

A fundamental aspect of experimental research is the active manipulation of the independent variable(s) by the researcher. This manipulation enables the detection of the effect on the dependent variable(s) as a causal relationship (Koch et al., 2019). In Study 2, the variables of interest, including gain and loss message framing, picture valence, and technology issues, were systematically manipulated in the newspaper articles and evaluated for their impact on attitudes, such as support and behavioral intentions towards emerging technologies. Furthermore, experimental designs allow for the control of confounding variables through the implementation of random assignments to stimuli and participants to experimental conditions, thereby ensuring that disparities in the dependent variable are attributable to the manipulation of the independent variable rather than other extraneous factors (Shadish, 2001).

Study 2 employed a mixed experimental research design, with technology issues varying within individuals and additional experimental factors of message framing and picture valence varying between individuals. The factors of message framing and picture

valence were implemented in a factorial research design as crossed factors that combined the manipulation of those factor levels of the independent variables. As such, this experimental design offers several advantages, including the ability to analyze the independent variables to study their main effects and interaction effects. In the context of media framing research, factorial designs have been a staple of experimental investigations, given their capacity to manipulate both textual units and non-textual elements, such as pictures (Druckman et al., 2010; Mcleod et al., 2022).

In the present study, a *3x3 mixed factorial design* with two fully crossed between-subjects factors was employed to assess the impact of gain and loss message framing, as well as the congruency with picture valence. Therefore, the experimental factors were 3 *message framing* (gain/loss/neutral framing) x 3 *picture valence* (positive/negative/no picture). This resulted in nine possible combinations of framing and picture valence. Moreover, the nature of the framing and picture valence were randomized for each participant. Similar as in other studies (for example Finucane et al., 2000), the technology issues constituted an additional within-subjects factor⁵⁷, where participant received a randomized combination of framing and picture valence in each condition of the five technology issues. Overall, this procedure resulted in 45 possible combinations of stimuli.

Table 10 provides an overview of the data structure for study 2 on message effects, referring to participants exposed to all levels of the within-person factor (technology topics) which shows observations on the responses to the outcome variable to each technology issue with randomized combinations of the two between-subjects factors (message framing and picture valence). The combinations of factor levels resulted in a total of 1,570 observations by the 314 participants.

⁵⁷ However, given that each technology issue was exclusively paired with a single combination of framing and picture valence for each stimulus, the technology issue factor was not fully crossed with message framing and picture valence.

Table 10. Example of the crossed data structure for the second study relating to message effects

Participant	Technology issue	Message framing	Picture valence	Support
1	Biofuels	Gain	Positive	5.7
1	Electric vehicles	Loss	Negative	4.3
1	Personalized medicine	Neutral	No Picture	5.4
1	Functionally graded materials (FGMs)	Gain	No Picture	4.3
1	Precision agriculture	Loss	Positive	4.1
2	Biofuels	Loss	Negative	5.7
2	Electric vehicles	Neutral	Positive	6.4
2	Personalized medicine	Gain	No Picture	3.5
2	Functionally graded materials (FGMs)	Neutral	Negative	5.8
2	Precision agriculture	Gain	Positive	4.6

The response scores provided for the outcome variable of support towards emerging technologies show exemplary measures for two participants over the stimuli of technology issues crossed with the experimental manipulation of message framing and picture valence.

6.2.2 Experimental Manipulation

A body of research in the field of science communication studies has demonstrated that message characteristics influence attitudes towards emerging technologies of various kinds, such as energy technologies (H. J. Kim, 2018) or nanotechnology (Cobb, 2005). However, the majority of these studies have focused on testing technology issues in isolation. In the second study on message framing, newspaper articles were displayed within the layout of newspaper pages, with randomized combinations of five technology issues and a combination gain and loss framing and picture valence. In each *text condition*, the news article briefly described the technology. Accordingly, in the gain and loss framing conditions, two or three sentences were shown to highlight the intended goal framing about the gains of using the technology or the losses of not using the technology. As recommended by Levin et al. (1998), the most extreme contrast in terms of valence was employed, designated as cross-complement goal framing. Regarding this framing condition, the consequences of the behavior were presented as a gain, while the failure to engage in the behavior was portrayed as a loss. For instance, the gain-framed condition concerning biofuels was articulated as follows: "Using sustainable biofuels made from

plants or animal by-products can significantly reduce greenhouse gas emissions." Conversely, the loss-framed condition stated: "Not using sustainable biofuels from plants or animal by-products can significantly increase greenhouse gas emissions."

In this study, the picture condition was associated with positive or negative valence, as evidenced using stock photographs related to technology. Conversely, the imagery employed was either positive, characterized by the use of bright colors and shades, and elements indicative of advancements, such as sustainable gasoline. Negative imagery was characterized by the use of darker colors and shades, which symbolized drawbacks such as environmental pollution from factories. As demonstrated in Figure 29, in conjunction with textual stimuli of varying valence, the valence of the picture either reflected the emotional valence of the textual framing (congruent condition) or contrasted with the emotional valence of framing (non-congruent condition). For instance, in the congruent condition, the text highlighted the benefits of biofuels, which was paired with a congruent picture of positive valence that accentuated the positive outcomes associated with biofuel technology. Conversely, in the non-congruent condition, the text emphasized the advantages of biofuels, which was paired with a non-congruent picture of negative valence, depicting a combustion plant and thus highlighting the potential negative environmental consequences associated with the loss argument of not using biofuels and instead relying on fossil fuels. The control conditions did not display any image when combined with gain text framing, loss text framing, or the neutral text framing condition. Nevertheless, the latter condition was analogous to the concise introductory presentation about the technology employed in both the gain and loss text conditions.

It has been stated that the objective of experimental investigations in the domain of communication research is to detect causal relationships. Therefore, it is essential to prioritize a balance between internal and external validity to ensure transparency in methodological decisions and to meet research quality criteria (Koch et al., 2019; Trepte & Wirth, 2004). A critical factor in experimental designs is internal validity, which is defined as the ability to detect whether the experimental treatments make "a difference in this specific experimental instance" (Campbell & Stanley, 1967, p. 5). In this regard, the observed covariation between the presumed treatment and the presumed outcome reflects a causal relationship between those variables as they were manipulated or measured (Shadish, 2001). To confirm the efficacy of the manipulations and rule out the influence of unintended variables on the results (Greenwald, 1976), the newspaper articles employed in the study were made comparable in terms of length, style, complexity, and

visual presentation. This was done to avoid unintended variations between articles that were not part of the experimental manipulation to ensure that confounding variables, such as differences in writing style or the complexity of the arguments, did not affect participants' responses in ways unrelated to the intended experimental factors. To ascertain the comparability of the text conditions across the two framing types, adjustments were made to their typesetting and word length, yielding a range of text conditions from 45 to 96 words. Consequently, the implementation of manipulation checks was imperative to confirm that the participants' perceptions aligned with the intended manipulation (Greenwald, 1976).

Using a set of media stimuli and pictures, this study evaluated the experimental manipulation of gain and loss framing and the valence of pictures in newspaper texts to test valence ratings. Based on the reported descriptive results of study 1 regarding subjective knowledge and subjective relevance perception towards the 32 technology issues, eight technology issues were preselected as stimulus material for study 2. The selection of these issues was guided by their mean ratings across the dependent variables, with the lowest and highest ratings serving as the primary criteria. For the stimuli material, the technology issues that were preselected included electric vehicles, nanotechnology, blockchain technology, biofuels, precision agriculture, personalized medicine, high-performance plastics, and functionally graded materials (FGMs).

A pilot study was conducted from March 18-22, 2022, with a sample size of 141 participants, recruited through the panel service Bilendi & Respondi (2024). The pretest tested a range of text conditions, including gain-framed and loss-framed options, along with picture conditions that featured positive and negative valence. These combinations of message framing and valence of the picture were embedded in eight different technology issues. If the text framing was perceived as intended, then gain text framing was rated as more positive than loss text framing. Conversely, if the pictures were perceived as intended, pictures of positive valence were perceived as more positive than pictures of negative valence. In the instances of electric vehicles and precision agriculture, the text conditions did not exhibit significant disparities in ratings between gain and loss framing, while the corresponding picture valence was perceived as intended. Consequently, minor adjustments were implemented to the text conditions to explicitly frame the issue in terms of gains and losses of the message. For the main study, five technology issues were selected based on their consistent ratings across conditions in the pre-test. These technology issues included electric vehicles, biofuels, functionally graded materials (FGMs),

personalized medicine, and precision agriculture (see [online appendix](#) for all stimuli materials of study 2).

Moreover, the random assignment of participants to experimental groups in the studies ensured that systematic variations in individual characteristics across experimental groups were minimized. Moreover, the employment of control conditions serves to ensure that observed differences in responses can be attributed directly to the manipulation rather than to other factors (Shadish, 2001). In the context of the text conditions, this was achieved by omitting indications of specific framing and employing neutral framing on the technology in the control condition. Consequently, the control condition for picture manipulations exhibited no images.

In addition to internal validity, researchers discuss its trade-off in experimental studies with the principles of *external validity* and the generalizability of effects (Campbell & Stanley, 1967). External validity can be defined as the validity of inferences about whether the causal relationship holds over variations in individuals, settings, treatment variables, and measurement variables (Shadish, 2001, p. 507). This concept is closely related to the notion of *ecological validity*, which pertains to the extent to which experimental findings can be generalized to real-world settings. In the context of media research, for instance, researchers must construct realistic and representative stimuli, such as news articles, to ensure external validity (Nowak, 1972). The newspaper stimuli for this study were constructed in the basic layout of an online newspaper page, but without specifying a particular media outlet or corporate design, so as not to distract from the content of the articles. Considering the context of media reception, the experiments were not conducted in a laboratory setting, but rather in the participants' private settings, which limited the researchers' control over external factors. However, this reception situation can be argued as a realistic setting for recipients to engage with multiple newspaper articles, which is also an advantage of the mixed research designs used to have greater external validity than between-subjects designs (Greenwald, 1976). To ensure the thoughtful completion of the online questionnaire, respondents with response times under five minutes were excluded from the study sample.

6. Study 2: Message Framing Effects

Figure 29. Stimulimaterial newspaper conditions for study 2

Benefits of Biofuels

Biofuels are often presented as an alternative to fossil fuels. Starting materials are natural resources such as corn, sugar cane or rapeseed oil. The most common biofuels are ethanol and biodiesel, which can be used as transport fuels.

Concerns about climate change and calls for sustainable alternatives to polluting fossil fuels have been raised over the past decade. Using sustainable biofuels made from plants or animal by-products can significantly reduce greenhouse gas emissions. By reusing resources that occur naturally in the manufacturing process of industrial production, biofuel also combats the highly relevant environmental problem of waste. It is estimated that using biofuels instead of fossil fuels will lead to cheaper gas prices in the long term.



Congruent condition with gain framing message and picture of positive valence

Benefits of Biofuels

Biofuels are often presented as an alternative to fossil fuels. Starting materials are natural resources such as corn, sugar cane or rapeseed oil. The most common biofuels are ethanol and biodiesel, which can be used as transport fuels.

Concerns about climate change and calls for sustainable alternatives to polluting fossil fuels have been raised over the past decade. Using sustainable biofuels made from plants or animal by-products can significantly reduce greenhouse gas emissions. By reusing resources that occur naturally in the manufacturing process of industrial production, biofuel also combats the highly relevant environmental problem of waste. It is estimated that using biofuels instead of fossil fuels will lead to cheaper gas prices in the long term.



Non-congruent condition with gain framing message and picture of negative valence

6.2.3 Procedure and Measures

Following the establishment of data collection procedures, participants were prompted to provide information regarding their sociodemographic characteristics, including gender, age, and education level. In the online questionnaire, participants were presented with

newspaper articles pertaining to each of the five technology issues. The stimuli comprised articles with manipulated gain and loss message framing, and pictures with different valences, which collectively constituted the message congruency variable. Respondents then answered to items designed to assess support and behavioral intentions concerning these issues. Furthermore, the survey assessed participants' predispositions (subjective knowledge, subjective relevance perception and message valence perception) as moderators of support and behavioral intentions.

To estimate the reliability of constructs with at least two items, a multilevel approach was used to account for both within-group (individual-level) and between-group (group-level) variances. This approach has been discussed as being crucial for capturing meaningful variance at the group level, as for example recommended by Geldhof et al. (2014) through the use of multilevel confirmatory factor analysis (MCFA). In this study, reliability at each level was assessed using McDonald's Omega (ω), specifically calculated through the `omegaSEM` function from the `multilevelTools` package in R (Wiley, 2025). For constructs such as technology support, the items were consistently measured for each participant, but they varied according to the specific technology being evaluated. The between-level Omega ($\omega_{between}$) was used to quantify the extent to which variance in the measured variable is attributable to differences between groups. This analysis yielded substantial insights into the reliability of the aggregated scores across different participants, indicating how consistently these scores reflect the underlying construct at the group level. Additionally, the within-level Omega (ω_{within}) was indicative of the reliability of measurement for individual participants. It quantified how much of the variance in item responses to technology items could be attributed to individual differences, rather than random measurement error. A high ω_{within} value suggests that the items consistently reflect the underlying construct for each participant. The attitude measures were derived from previous studies and will be summed up in what follows.

Support towards emerging technologies

In order to assess the level of *support* towards the emerging technologies, measures were adapted from studies by C. Lee and Scheufele (2006) and Brossard and Nisbet (2007). Two items on a 7-point- scale, ranging from 1 = strongly disagree to 7 = strongly agree were employed, such as "There should be more federal funding for biofuels".

Table 11 provides an overview of the statistics for the measures employed in study 2. The overall level of support expressed by participants for emerging technologies was moderate ($M = 4.99$, $SD = 1.40$) (7-point scale). McDonald's Omega (ω) indicated high reliability, on the within-individual level ($\omega_{\text{within}} = 0.88$), and the between-individual level ($\omega_{\text{between}} = 0.95$). The ICCs for support of emerging technologies demonstrated variability at the individual level ($ICC = 0.38$), with minimal variability at the technology newspaper stimuli level ($ICC = 0.13$), suggesting that technology grouping did not introduce significant additional variance.

Behavioral intentions towards emerging technologies

To measure *behavioral intentions towards emerging technologies*, a set of four items, which were drawn from a scale developed C. Lee et al. 2006 were used. This scale examined the recipients' concrete intentions to support emerging technologies, with items such as "I will vote for a political party that supports biofuels." With respect to behavioral intentions concerning emerging technologies, moderate scores were identified ($M = 4.09$, $SD = 1.47$). The reliability of this measure was highly consistent across individuals ($\omega_{\text{between}} = .94$) and within individuals ($\omega_{\text{within}} = .84$). Furthermore, the ICCs for behavioral intentions towards emerging technologies exhibited greater variability at the individual level ($ICC = 0.45$) compared to the level of technology newspaper stimuli ($ICC = 0.12$).

Message valence perception

Moreover, the judgment of *message valence* was measured separately for text and image by three items with 7-point semantic differential items. These items were similar to those used by Seo and Dillard (2019), for example, "The message emphasized disadvantages/advantages." The perceived message valence ($M = 5.23$, $SD = 1.21$) showed moderate variability on the person level ($ICC = 0.47$) and small variability on the topic level ($ICC = 0.06$). Meanwhile, the reliability of the measure was consistent at a sufficient level within individuals ($\omega_{\text{within}} = .91$) and across individuals ($\omega_{\text{between}} = .97$).

Subjective knowledge of emerging technologies

The *subjective knowledge* of emerging technologies was assessed using a single item (European Commission, 2013; Yang et al., 2017). This item measured the self-perceived knowledge of respondents on a 7-point scale from 1 = strongly disagree to 7 = strongly

agree ("In general, I do feel well informed about..."). Overall, the subjective knowledge of technology issues was evaluated as moderate ($M = 4.09$, $SD = 1.78$), indicating moderate variability at the individual level ($ICC = 0.44$) and negligible variability at the technology stimulus level ($ICC = 0.13$).

Subjective relevance perception of emerging technologies

To measure the *subjective relevance perception* of emerging technologies, one item by Whitmarsh and O'Neill (2010) was used ("The article I read made me feel that Biofuels are important", 7-point-scale (1 = strongly disagree to 7 = strongly agree). The technology topics were perceived as moderately relevant by the participants ($M = 5.02$, $SD = 1.58$) with moderate variability on the person level ($ICC = 0.40$) and little variability on the level of technology issues ($ICC = 0.10$).

Covariates

Participants' level of *religiosity* and *political ideology* were assessed as additional control variables. The single-item measures were adapted from Anderson et al. (2014). For the assessment of religiosity, one item on a 10-point scale was employed, with respondents indicating their level of agreement with the following statement: "To what extent does religion provide guidance in your everyday life?" with possible responses ranging from 1 = "No guidance at all" to 10 = "A great deal of guidance" ($M = 3.56$, $SD = 3.05$). The measurement of political ideology entailed the use of a 6-point scale, with respondents being asked to indicate their level of agreement with the following statement: "Please indicate how socially liberal or conservative you are" from 1 = "Very liberal" to 6 = "Very conservative" ($M = 3.26$, $SD = 1.37$).

Table 11. Overview on the operationalization of measures and statistics for study 2

Construct	Statistics					
	<i>M</i>	SD	ICC (Person)	ICC (Tech)	ω_{within}	ω_{between}
<i>Message valence perception</i> (based on Seo & Dillard, 2019) Perceived message valence for text and picture: The message emphasized						
(1) Disadvantages/advantages	5.23	1.21	.47	.06	.91	.97
(2) Costs/Benefits						
(3) Negative consequences/Positive consequences						
<i>7-point semantic differential</i>						
<i>Subjective knowledge of emerging technologies</i> (based on European Commission, 2013; Yang et al., 2017)						
(1) In general, I do feel well informed about this technology.	4.09	1.78	.44	.13		
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)						
<i>Subjective relevance perception</i> (based on Whitmarsh & O'Neill, 2010)						
(1) The article I read made me feel that Biofuels are important.	5.02	1.58	.40	.10		
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)						
<i>Support emerging technologies</i> (based on C. Lee & Scheufele, 2006 and Brossard & Nisbet, 2007)						
(1) There should be more federal	4.99	1.40	.38	.13	.88	.95

6. Study 2: Message Framing Effects

funding for bio-fuels.							
(2) Overall, I support the use of biofuels.							
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)							
<i>Behavioral intentions emerging technologies</i> (based on C. Lee & Scheufele, 2006)							
(1) I will vote for a political party that supports Biofuels.	4.09	1.47	.45	.12	.84	.94	
(2) I will get personally involved to support Biofuels.							
(3) I would like to receive more information on how to take further action to support Biofuels.							
(4) I will use products that are linked to Biofuels.							
7-point-scale (1 = <i>strongly disagree</i> to 7 = <i>strongly agree</i>)							
<i>Religiosity</i> (based on Anderson et al., 2014)							
(1) How much guidance does religion provide in your everyday life?	3.56	3.05					
10-point-scale (1 = “no guidance at all” to 10 = “a great deal of guidance”)							
<i>Political ideology</i> (based on Anderson et al., 2014)							
(1) Please indicate how socially liberal or conservative you are.	3.26	1.37					
6-point-scale (1 = “very liberal” to 6 = “very conservative”)							

6.2.4 Sample and Power Analysis

For the second study on message effects on technology attitudes, data was collected from March 29 to April 4, 2022, through the panel service Bilendi & Respondi (2024). A sampling strategy for a British sample was used, aiming at balanced quotas for equal distribution by low, medium and high levels of formal education and gender. Conducting the mixed design for this study meant accounting for multiple conditions or stimuli encountered by each participant, as well as for both fixed effects (experimental manipulations) and random effects (participant- or item-specific variability). It can be argued that mixed designs often provide greater statistical power because repeated measures provide more information per participant, making such designs more efficient compared to between-subjects designs (Westfall et al., 2014).

An a priori power analysis was conducted with G*Power (Faul et al., 2007) which incorporated the nine experimental conditions as a between-subjects factor and the five technology conditions as repeated measures. This analysis indicated that, for a medium effect size ($f = 0.25$), a power level of .80, with an alpha level of 0.05, approximately 6 participants per group (for a total of 54 participants) were required to detect the interaction between groups and conditions due to the repeated measures design. Conversely, a comparable between-subjects design comprising 45 groups (representing combinations of framing, picture valence, and technology conditions) would necessitate 6 participants per group, resulting in a total sample size of 270 participants, to detect the same effect size. Assuming the effect size was $f = 0.1$, the between-subjects design would necessitate 36 participants per group, resulting in a total sample size of 1.620 participants. This design would be considerably less efficient in comparison to the mixed design, which would require 29 participants per group and a total sample size of 261 participants.

Consequently, for the second study, the decision was made to seek out a minimum of 261 participants to detect a small effect size at a power level of 80%, which was accomplished by recruiting $n = 320$ participants during the initial data collection phase. Following the collection of data, responses that lacked complete answers for the dependent variables and sociodemographic questions were excluded from the data set ($n = 6$). As shown in Table 12, the final sample comprised 314 respondents, with 50.0% identifying as male, 49.7% as female, and 0.3% as non-binary. The age range of the sample varied from 20 to 85 years ($M = 48.0$ years, $SD = 14.78$). Data further revealed that 21% of the sample had a low education level, with no high school diploma, while 57% had a high school diploma and 22% had a university degree.

Table 12. Sociodemographics of the sample for study 2 on message framing effects

<i>N</i> = 314		
Sample details		
	Frequency	Percentage
Gender		
Male	157	50.0%
Female	156	49.7%
Non-binary	1	0.3%
Age		
18-25	21	6.7%
26-35	52	16.6%
36-45	71	22.6%
46-55	60	19.1%
56-65	60	19.1%
>66	50	15.9%
Education		
No education diploma	66	21.0%
High School	179	57.0%
University Degree	63	20.1%
PhD	6	1.9%
Country of residence		
United Kingdom	314	100%

6.2.5 Data Analysis

As in study 1, the mixed-effects model structure was applied to account for repeated measurements within participants while accounting for the crossed design of independent variables (Baayen et al., 2008), such as text framing and picture valence. This methodological approach addressed variability within participants and across different technology stimuli, thereby enabling a comprehensive analysis of the experimental conditions' effects. Linear mixed-effects models were conducted using the lme4 package in R (Bates et al., 2015) for data analysis. Within the statistical models, random intercepts were specified for participants and technology stimuli to capture baseline differences specific to each participant and stimulus. Although for example Barr (2013) generally advocated for a maximal random-effects structure that includes random slopes for within-unit predictors, including such slopes was deemed impractical in this study due to the small number of stimuli (five technology issues) and the fully crossed design. Each participant was

exposed to all five stimuli under all fixed-effect conditions, limiting systematic variability and making slope estimation unstable. Therefore, the final model included random intercepts only, which was justified as the most appropriate maximal random-effects structure given the design. Moreover, the categorical predictor variables were treatment-coded (Wendorf, 2004), with reference categories selected based on their theoretical relevance. For example, in the case of the variable representing gain and loss framing, the baseline category was neutral framing. In this random intercept model, the intercept represents the mean response (e.g., support or behavioral intentions) for the reference category, neutral framing, while the regression coefficients indicate the mean differences between neutral framing and the gain and loss framing conditions.

As Figure 30 shows, two baseline models with random intercepts by participants and technology stimuli were conducted, predicting the dependent variables of *support* and *behavioral intentions towards emerging technologies*. The objective of this analysis was to detect the basic variance estimates on the level of persons and technology stimuli (RQ2.1). In the initial phase of the data analysis, two mixed models were employed. These models incorporated the experimental manipulation of gain and loss framing in text and valence in pictures as fixed effects terms, along with interaction terms between these two factors. In addition, the control condition of neutral framing and the absence of pictures were employed as the reference category to predict the influence on support and behavioral intentions (see step 1 of data analysis). This approach was undertaken to identify the impact of gain or loss framing in text (RQ2.2) and positive or negative picture valence (RQ2.3) on support and behavioral intentions.

To facilitate interpretation, average marginal effects (AMEs) were computed using the `avg_predictions` function from the `marginalEffects` R package (Leeper, 2024). AMEs were calculated by predicting the outcome for each observation under each level of the independent variable and averaging the resulting marginal effects across all observations. This approach provides an interpretable estimate of the mean effect across participants and stimuli. For text framing, AMEs indicate the average difference in responses relative to neutral framing, while for picture valence, AMEs reveal the average effect of presenting an image of different valence compared to no image. All AMEs were accompanied by 95% confidence intervals to quantify uncertainty in the estimates (Arel-

Bundock et al., 2024)⁵⁸.

In order to test the hypotheses *H2.1-H2.4* concerning the congruency of message framing and picture valence, average marginal contrasts were conducted to compare the predicted effects of different experimental conditions. The `avg_comparisons` function from the R package `marginaleffects` (Arel-Bundock et al., 2024) was used to conduct this analysis. This method entails the estimation of mean differences between subgroups specified by combinations of text framing (gain vs. loss) and picture valence (positive vs. negative). Specifically, the analysis calculated predicted outcomes for each observation in the dataset under the various combinations of text framing and picture valence. These individual-level predictions were then averaged within each condition to generate subgroup means, representing the expected outcomes for each condition while accounting for other model factors. Subsequently, contrasts between these subgroup means were computed to assess differences in support and behavioral intentions across the experimental conditions. This function estimates contrasts (differences or comparisons) of average marginal effects for specific group combinations and generates statistical metrics (e.g., standard errors, confidence intervals) to evaluate the significance of these contrasts.

As specified in *H2.5*, potential interaction effects for the combinations of *message framing congruency* and *prior attitudes* on the outcome variables of attitude formation were tested. Prior attitudes of respondents were further evaluated as *message valence perception*, *subjective knowledge* of emerging technologies, and *subjective relevance perception* toward emerging technologies. Moderator variables were tested for their interaction with message congruency between text and pictures on support and behavioral intentions. As part of the data analysis of interaction effects, the text and picture combinations in each condition were transformed into a single variable representing the message congruency of the text and picture. These conditions were further categorized as *congruent* or *non-congruent* based on the congruency of message valence between text and picture. Therefore, congruent conditions involved a gain-frame text accompanied by a positive picture or a loss-frame text with a negative picture, and non-congruent conditions showed a gain-frame text accompanied by a negative picture or a loss-frame text with a positive

⁵⁸ As Leeper (2024) has argued, Average Marginal Effects (AMEs) summarize effects by averaging across all individuals, reflecting the full data distribution. In contrast, Marginal Effects at Means (MEMs) use mean covariate values, which may be unobserved or arbitrary. AMEs therefore can be argued to provide a more representative summary of the effects in the sample.

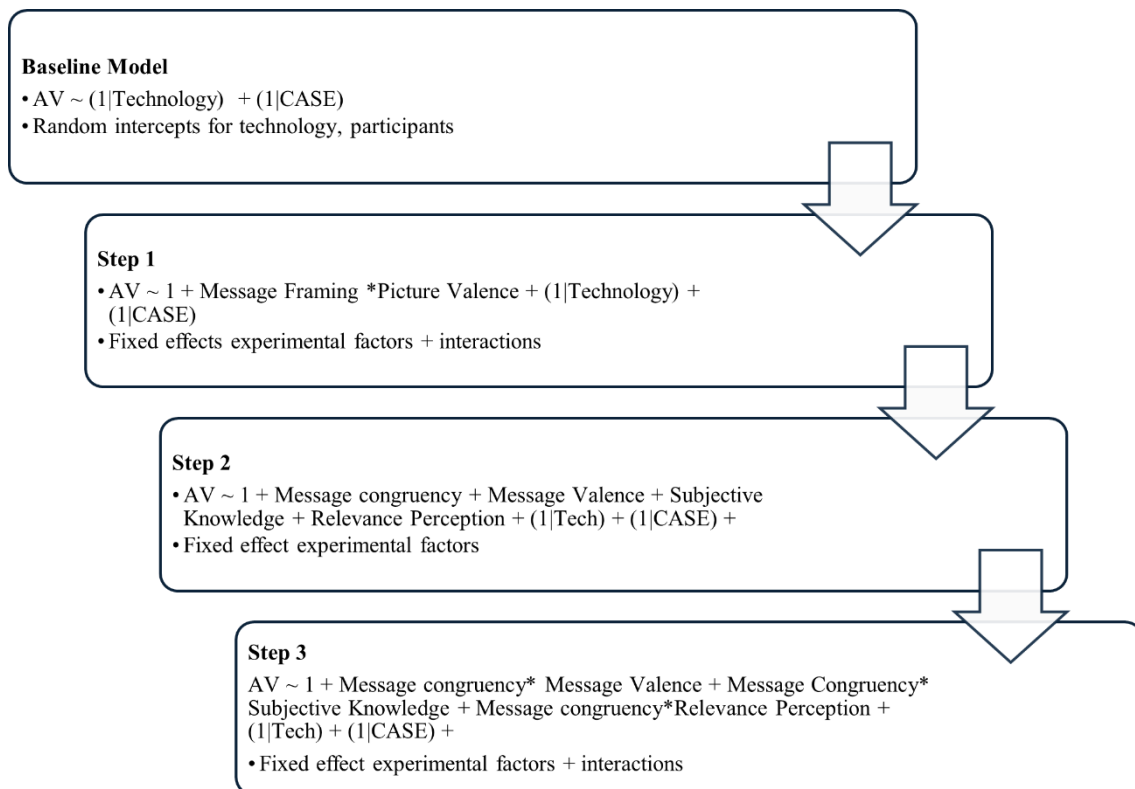
picture. Subsequent to the exclusion of the control condition, which exhibited neutral framing or an absence of a picture, this analysis encompassed a total of 669 observations from 289 participants.

As recommended by Bates et al. (2015), model comparison statistics were conducted to estimate the model fit of the interaction models. These statistics were then compared to the main-effects-only models of the predictors and moderator variables. As the correlations of the moderator variables (perceived message valence, subjective knowledge, and subjective relevance perception) did not suggest multicollinearity ($r < .66$), all variables and their interactions with message congruency were included in the models explaining support and behavioral intentions toward emerging technologies. According to Figure 30, the model fit was assessed by implementing a mixed-effects model comprising the main effects of the predictors and moderator variables without interactions (step 2), followed by an additional model that incorporated the same predictors and moderator variables with interactions as fixed effects (step 3).

An assessment of model fit was conducted through the implementation of a likelihood-ratio test, which was executed with the utilization of the ANOVA function in R. This function is founded upon the F-test and employs maximum likelihood estimation. Consequently, the model's fit was determined by the statistical significance of the likelihood-ratio test. If the p-value was found to be significant ($p < .05$), it was indicative of a superior fit for the data when the full model with interactions was employed, as opposed to the model without interactions. Conversely, if the interaction models did not yield a better fit, results from the main-effects models were reported for the results. A likelihood-ratio test compared a random-intercept model including only the fixed effects of message congruency and prior attitude variables to a model additionally including their interactions predicting support towards emerging technologies. The model with interactions provided a significantly better fit to the data than the simpler model, $\chi^2(3) = 15.02, p = .001$. Model fit indices also improved (Deviance reduced from 2033.4 to 2018.3, AIC reduced from 2049.4 to 2040.3), indicating that including the interaction terms increased explanatory power. For behavioral intentions towards emerging technologies, a likelihood-ratio test comparing a random-intercept model with only the fixed effects of message congruency and prior attitude variables to a model additionally including their interactions was not significant, $\chi^2(3) = 7.68, p = .053$. Model fit indices showed only minor improvements (Deviance decreased from 1942.1 to 1934.4, AIC from 1958.1 to 1956.4). Given the trend toward improved fit, the model with interactions was nevertheless retained for further

analyses. In order to calculate effects between message framing congruency and the moderator variables, the conditional effect of message congruency on the moderator variables was estimated through modeling the interaction effects. To illustrate this, the effects of message congruency across different levels of the moderating variables were conducted, which show how the average slope of message congruency varies depending on the level of the moderator variables. For the 7-point scales of the outcome variables (support and behavioral intentions), the low level of moderator variables was defined as the scale point of =1, the medium level as = 4, and the high level as = 7.

Figure 30. Data analysis plan study 2 for the mixed effects data structure with stepwise inclusion of fixed effects



6.3 Results

This section gives an overview of the results of the second empirical study of message effects on attitudes toward emerging technologies. In the following, the results refer to the influence of the person level and the issue level on support and behavioral intentions (6.3.1). In addition, message framing and message congruency effects are evaluated

(6.3.2). Finally, results on interaction effects between message congruency and respondents' prior attitudes on attitudes are presented (6.3.3).

6.3.1 The Influence of Person-level and Topic-level differences

Referring to *RQ2.1*, two intercept-only models were specified without fixed effects, including only random intercepts for participants and technology stimuli to predict the outcome variables of support and behavioral intentions toward emerging technologies (see [online appendix](#) the baseline models). The variance components of the mixed models for the dependent variables are summarized in Table 11. For the model predicting support, the total variance was 2.24, with the largest part of the variance of support being the residual (49%), the variability between participants contributed to 38% of the total variance, while variability between technology newspaper articles for 13% of the total variance. These ICC values suggest a moderate level of agreement among individuals regarding their support of emerging technologies and the variability attributable to technology stimuli was minimal.

For the model predicting behavioral intentions, the total variance was 2.34, with the largest contributor to the variance being differences between participants, explaining 45% of the total variance, while technology stimuli explained 12% of the total variance, leaving 43% of the variance unexplained. These variance estimates suggest that the mixed effects model structure was justified for both dependent variables. Overall, the person-level variance in answering *RQ2.1* is greater than the variance between technology stimuli, indicating that individual differences play a significant role in shaping support and behavioral intentions toward emerging technologies.

6.3.2 Message Framing and Message Congruency Effects

Before elaborating further on the relationship between the independent variables and attitudes towards emerging technologies, descriptive measures were calculated for the newspaper conditions. As indicated in Table 13, the respondents indicated their relatively high support for the technologies under investigation. The respondents reported high *support* for personalized medicine ($M = 5.24$, $SD = 1.37$) and biofuels ($M = 5.21$, $SD = 1.56$) but assigned lower ratings to functionally graded materials ($M = 4.49$, $SD = 1.25$). In terms of *behavioral intentions*, personalized medicine received the highest mean ratings ($M = 4.48$, $SD = 1.37$), while functionally graded materials garnered the lowest ratings

($M = 3.67$, $SD = 1.41$). Given the objective of the study to identify the impact of gain and loss framing in the newspaper text condition (*RQ2.2*), the effect of the valence of pictures (*RQ2.3*), and the congruency of both factors (*H2.1-H2.4*) on the dependent variables of support and behavioral intentions, a comparative analysis was conducted of the conditions in terms of their mean ratings. With respect to the message congruency conditions, the congruent condition, which combined gain framing with a positive picture, received the highest mean ratings for both support ($M = 5.29$, $SD = 1.36$) and behavioral intentions ($M = 4.32$, $SD = 1.58$). This finding indicates that this combination is particularly effective in eliciting positive attitudes towards the technologies. In contrast, the neutral framing with a negative picture condition elicited the lowest mean ratings for both support ($M = 4.63$, $SD = 1.40$) and behavioral intentions ($M = 3.94$, $SD = 1.47$).

Table 13. Means and standard deviations of dependent variables for experimental conditions

Condition	<i>n</i>	Support	Behavioral intentions
Newspaper articles issues			
Biofuels	314	5.21 (1.56)	4.23 (1.46)
Electric vehicles	314	5.13 (1.39)	4.16 (1.60)
Functionally graded materials	314	4.49 (1.25)	3.67 (1.41)
Personalized medicine	314	5.24 (1.37)	4.48 (1.37)
Precision agriculture	314	4.87 (1.32)	3.93 (1.38)
Message congruency			
Gain framing/positive picture	173	5.29 (1.36)	4.32 (1.58)
Gain framing/negative picture	175	5.21 (1.34)	4.16 (1.47)
Gain framing/no picture	173	5.01 (1.32)	4.12 (1.35)
Loss framing/positive picture	176	4.97 (1.48)	4.07 (1.52)
Loss framing/negative picture	176	5.15 (1.39)	4.20 (1.44)
Loss framing/no picture	173	5.10 (1.39)	4.02 (1.42)
Neutral framing/positive picture	174	4.78 (1.42)	3.98 (1.46)
Neutral framing/negative picture	175	4.63 (1.40)	3.94 (1.47)
Neutral framing/no picture	175	4.77 (1.45)	4.03 (1.51)

$N = 314$ respondents, $n = 1,570$ observations. Means and standard deviations for the average responses of participants for the technology newspaper conditions and the combination of message framing and picture valence (message congruency) concerning the dependent variables of support and behavioral intentions.

Bivariate correlations were conducted to examine how the dependent variables of support and behavioral intentions vary across participants and across different technology conditions. As shown in Table 14, the correlations between the technology conditions and support were, in general, moderate. The strongest correlation was observed between biofuels and electric vehicles ($r = .55, p < .001$), indicating that participants who support one technology are likely to support the other as well. In contrast, the weakest correlation was found between functionally graded materials and biofuels ($r = .21, p < .001$), suggesting a relatively weaker association. Overall, the results suggest a moderate level of consistency in participants' support for the different technologies, with some conditions (e.g., biofuels and electric vehicles) showing stronger correlations, while others (e.g., functionally graded materials) demonstrate weaker associations. This pattern suggests that, while participants' responses to the technologies differed, there were underlying similarities in their support for different technology conditions.

As indicated by Table 15, the correlations between behavioral intentions toward the five emerging technologies indicate that participants who express behavioral intentions to support one technology are likely to express similar intentions toward others. The strongest correlations were observed between functionally graded materials and precision agriculture ($r = .65, p < .001$), followed by biofuels and precision agriculture ($r = .59, p < .001$). The correlation between electric vehicles and precision agriculture ($r = .46, p < .001$) revealed comparatively weaker behavioral intentions toward these technologies. Generally, the results showed moderate correlations between technology, with functionally graded materials and precision agriculture demonstrating the strongest alignment with participants' behavioral intentions.

Table 14. Bivariate correlations between technology conditions and support towards emerging technologies

Technology condition	Biofuels	Electric vehicles	Functionally graded materials	Personalized medicine	Precision agriculture
Biofuels	1.00	.55***	.21***	.30***	.43***
Electric vehicles	.55***	1.00	.31***	.30***	.43***
Functionally graded materials	.21***	.31***	1.00	.33***	.43***
Personalized medicine	.30***	.30***	.33***	1.00	.45***
Precision agriculture	.43***	.43***	.43***	.45***	1.00

Pearson's r correlations, *** $p < .001$, $n = 314$

Table 15. Bivariate correlations between technology conditions and behavioral intentions towards emerging technologies

Technology condition	Biofuels	Electric vehicles	Functionally graded materials	Personalized medicine	Precision agriculture
Biofuels	1.00	.58***	.54***	.54***	.59***
Electric vehicles	.58***	1.00	.49***	.48***	.46***
Functionally graded materials	.54***	.49***	1.00	.53***	.65***
Personalized medicine	.54***	.48***	.53***	1.00	.57***
Precision agriculture	.59***	.46***	.65***	.57***	1.00

Pearson's r correlations, *** $p < .001$, $n = 314$

As Table 16 indicates (see Model 1), the first linear mixed model with support as outcome variable predicted the effect of gain and loss framing and the valence of picture which was specified with fixed effects for gain and loss framing and valence of picture, as well as the interaction of these variables. The mixed model predicting support including the fixed effects of message framing and picture valence showed a minimal increase (1%) in total explained variance (conditional $R^2 = 0.41$). Therefore, compared to the null model without fixed effects, notably only 1% of the variance in support was explained by the fixed effects of message framing and picture valence. In this model, loss framing showed a significant positive effect on support ($b = 0.40$, 95% CI = [0.16, 0.65], $p = .001$). Conversely, as indicated in Table 16 (Model 2), the mixed model predicting the framing effect of gain and loss framing and the valence of pictures on behavioral intentions as the dependent variable also showed no substantial increase in the variance of behavioral intentions (marginal $R^2 = 0.002$).

Table 16. Results of the linear mixed-effect models predicting support and behavioral intentions towards emerging technologies

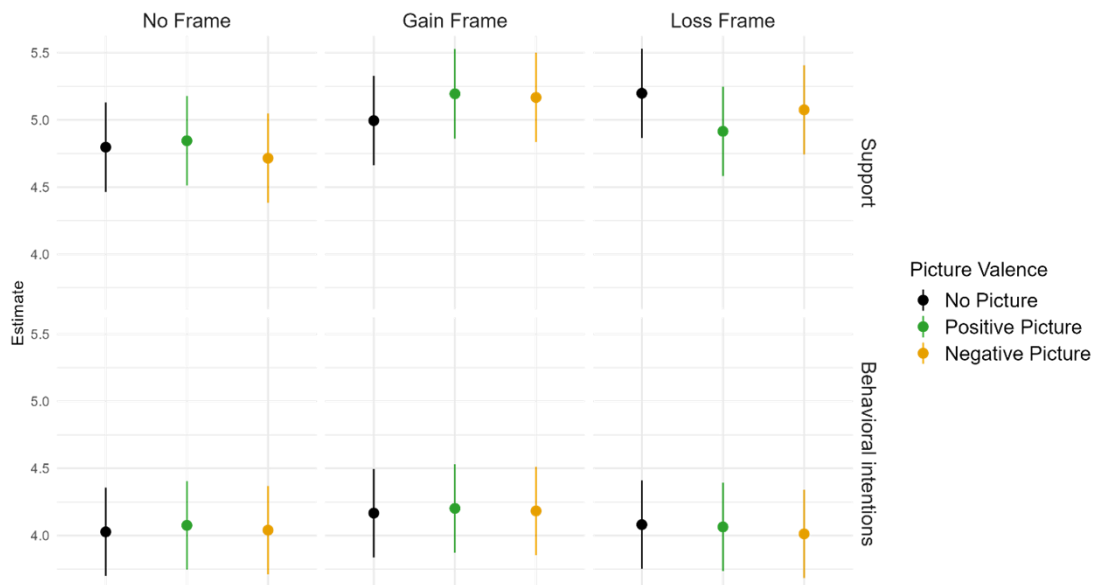
	Model 1		Model 2	
	<i>b</i>	95% <i>CI</i>	<i>b</i>	95% <i>CI</i>
Fixed effects				
Gain framing	0.20	-0.05 – 0.44	0.14	-0.08 – 0.36
Loss framing	0.40***	0.16 – 0.65	0.05	-0.17 – 0.28
Positive picture	0.05	-0.20 – 0.29	0.05	-0.17 – 0.27
Negative picture	-0.08	-0.32 – 0.16	0.01	-0.21 – 0.24
Gain framing x positive picture	-0.15	-0.20 – 0.50	-0.01	-0.33 – 0.31
Loss framing x negative picture	-0.04	-0.39 – 0.30	-0.08	-0.40 – 0.24
Gain framing x negative picture	0.25	-0.09 – 0.60	0.00	-0.31 – 0.32
Loss framing x positive picture	-0.33	-0.68 – 0.01	-0.07	-0.38 – 0.25
Message congruency (non-congruent)	-0.42	-1.18 – 0.35	0.09	-0.58 – 0.75
Message valence perception	-0.02	-0.15 – 0.10	0.07	-0.04 – 0.18
Subjective personal relevance per- ception	0.48***	0.37 – 0.60	0.51***	0.40 – 0.61
Subjective knowledge	0.11**	0.04 – 0.19	0.15***	0.07 – 0.22
Message congruency (non-congruent) x message va- lence perception	0.28***	0.11 – 0.45	0.14	-0.01 – 0.29
Message congruency (non-con- gruent) x subjective personal rele- vance perception	-0.10	-0.25 – 0.04	-0.18**	-0.31 – -0.05
Message congruency (non-con- gruent) x subjective knowledge	-0.14**	-0.24 – -0.03	0.04	-0.05 – 0.13

$N = 314$, $n = 1,570$ observations for the mixed model including gain and loss text framing and picture valence conditions with interactions. The mixed model with fixed effects of message congruency included $n = 669$ observations by $n = 289$ participants, because the conditions with neutral framing and no picture ($n = 901$ observations) were excluded from this analysis. Non-standardized regression coefficients are reported. Reference groups for the categorical variables: gain framing/loss framing = neutral framing; positive picture/negative picture = no picture; message valence non-congruent = message valence congruent.

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

In order to estimate the effects on the outcomes for different levels of the message framing and picture valence conditions, average marginal predictions (*AMEs*) were conducted. As shown in Figure 31, for the outcome of support, the highest estimate was found in the gain frame condition combined with a positive picture ($AME = 5.19$, 95% CI [4.86, 5.53], $p < .001$), while the lowest estimate was found in the neutral frame condition combined with a negative picture ($AME = 4.72$, 95% CI [4.38, 5.05], $p < .001$). For the behavioral intention outcome, the highest estimate was evident in the gain frame with positive picture condition ($AME = 4.20$, 95% CI [3.87, 4.53], $p < .001$), compared to the lowest estimate in the loss frame with negative picture condition ($AME = 4.01$, 95% CI [3.86, 4.34], $p < .001$). Overall, these findings suggest that positive message framing and imagery significantly increase participants' support for emerging technologies, while negative framing and imagery contribute to lower levels of support and behavioral intentions in response to *RQ2.2* and *RQ2.3*.

Figure 31. Average marginal effects for text framing conditions and picture valence predicting support and behavioral intentions towards emerging technologies



$n = 314$. Average marginal effects for support and behavioral intentions toward emerging technologies (scale: 1 = strongly disagree; 7 = strongly agree), based on framing text conditions and picture valence. The values were estimated for 95% CI for mean support and behavioral intentions.

Message presentation congruency

In the next step of the analysis, potential message congruency effects between the two independent variables, gain and loss text framing and picture valence, were considered. As hypothesized in *H2.1*, newspaper articles on the topic of emerging technologies with gain-framed messages and paired with an image of positive valence were expected to increase attitude measures of support and behavioral intentions to a greater extent than a control condition without framing and no picture shown. To represent the effect of the outcome variables on the factor levels of the gain and loss text framing and picture valence variables specified in *H2.1*, comparisons were conducted with average contrasts between the two variables to show average differences.

Table 17 indicates that neutral text framing without a picture was associated with significantly lower support than gain framing and a picture of positive valence ($mdiff = -0.40$, $p = .045$). However, the association did not hold for behavioral intentions ($mdiff = -0.17$, $p = .99$), thus partially confirming *H2.1* for support towards emerging technologies.

Following *H2.2*, the pair of a gain-framed text and a positive-valenced picture (congruent-valence) compared to the pair of a gain-framed text and a negative-valenced picture (non-congruent valence) showed not to vary in mean differences for support ($mdiff = 0.03$, $p = .99$) or behavioral intentions ($mdiff = 0.02$, $p = .99$). Based on these results, *H2.2* was rejected for the outcome variables of support and behavioral intentions.

Furthermore, it was predicted that a message-congruent contrast of a loss-framed message which is paired with a picture of negative valence would increase support and behavioral intentions toward a technology more than neutral framing and no image control condition (*H2.3*). As indicated in Table 17, the contrast of loss framing and negative valenced picture compared to neutral framing and no picture did not show a statistically significant difference between the conditions for support ($mdiff = -0.28$, $p = .59$), as well as behavioral intentions ($mdiff = 0.01$, $p = .99$), so *H2.3* was rejected.

The next contrast tested was the non-congruent conditions of loss framing and gain framing, as opposed to the congruent conditions of loss framing and negative picture (*H2.4*). In this case, the noncongruent loss-framed-positive picture conditions led to lower support than the congruent loss-framed-negative picture conditions, but this effect did not reach statistical significance ($mdiff = -0.16$, $p = .99$) (see Table 17). For behavioral intentions, the direction of the effect was reversed, as the non-congruent conditions led to higher behavioral intentions than the congruent conditions, but this effect was also not statistically significant ($mdiff = 0.05$, $p = .46$), thus rejecting *H2.4*. Overall, the hypotheses

comparing message framing and picture valence (congruent vs. non-congruent conditions) were mostly rejected. However, it was confirmed that gain-framed messages paired with a positive picture increased support compared to neutral message framing without a picture.

Table 17. Estimated contrasts comparing message congruency levels concerning support and behavioral intentions towards emerging technologies

		Support		Behavioral intentions	
Level 1	Level 2	Difference	95% CI	Difference	95% CI
Neutral frame/ no picture	Gain frame/ positive picture	-0.40*	-0.77 – -0.03	-0.17	-0.52 – 0.17
Gain frame/ positive picture	Gain frame/ negative picture	0.03	-0.35 – 0.40	0.02	-0.32 – 0.36
Neutral Frame/ no Picture	Loss frame/ negative picture	-0.28	-0.65 – 0.09	0.01	-0.32 – 0.35
Loss frame/ positive picture	Loss frame/ negative picture	-0.16	-0.53 – 0.21	0.05	-0.29 – 0.39

Marginal contrasts were estimated at the levels of message framing and picture valence, p-value adjustment correction by Holm-Bonferroni (Holm, 1979) for multiple testing of comparisons.

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

6.3.3 Moderators of Message Congruency Effects

As indicated in *H2.5*, it was tested whether the congruency of gain and loss framing and picture valence interacted with moderator variables to influence support for and behavioral intentions toward emerging technologies. In a first step it was assessed how strongly the moderator variables correlate with each other in terms of being statistically differing from each other, which was relevant to avoid multicollinearity issues when including all moderator variables in one statistical model estimation (see also chapter 6.2.5). Table 18

implies the Pearson's correlation coefficients between message valence, subjective knowledge, and subjective relevance, based on 289 participants of the subset without control conditions. A moderate positive correlation was found between perceived message valence and subjective knowledge of the technology issues ($r = .39, p < .001$). Perceived message valence and subjective relevance perception showed a moderate positive correlation ($r = .66, p < .001$), indicating that higher perceived message valence is closely associated with greater subjective relevance perception of the technology issues. Moreover, the subjective knowledge of emerging technologies and the subjective relevance perception showed a moderate positive correlation ($r = .45, p < .001$). However, these moderate correlations of $r < .70$ between the moderator variables did not suggest that multicollinearity between the variables was too high (J. Cohen et al., 2003), which justified including the moderator variables in one statistical model.

Table 18. Bivariate correlations between moderator variables

Moderator Variables	Message valence perception	Subjective knowledge	Subjective relevance perception
Message valence perception	1.00	.39***	.66***
Subjective knowledge	.39***	1.00	.45***
Subjective relevance perception	.66***	.45***	1.00

Pearson's r correlations, *** $p < .001$, $n = 289$

Two linear mixed models with interaction effects of message congruency and the moderator variables of perceived message valence, subjective knowledge and subjective relevance perception as fixed effects were run for the dependent variables of support and behavioral intentions towards emerging technologies. As shown in Table 16, Model 1, the total variance explained was 44%, while the fixed effects explained 33% of the variance in support. Compared to the model with fixed effects of message framing conditions alone, this was an increase of 32% of the variance explained in support due to the inclusion of additional fixed effects of the moderator variables. The mixed model with

behavioral intentions as the dependent variable showed a total variance explanation of 70%, while 38% of the variance could be explained by the fixed effects (see Table 16 Model 2). Compared to the model with message framing effects only, this was an additional substantial increase of 36% in the variance of behavioral intentions.

As the model estimates in Table 16 show (see Model 1), the effect for message congruency (non-congruent message) indicated no significant difference compared to the reference category of a congruent message on technology *support* ($b = -0.42$, 95% CI = $[-1.18, 0.35]$, $p = .28$). The perceived message valence had no effect on support ($b = -0.02$, 95% CI = $[-0.15, 0.10]$, $p = .71$). However, subjective personal relevance perception showed a positive main effect on support ($b = 0.48$, 95% CI = $[0.37, 0.60]$, $p < .001$). Furthermore, the interaction between message congruency and perceived message valence resulted in a significant positive effect ($b = 0.28$, 95% CI = $[0.11, 0.45]$, $p = .001$). For message congruency and subjective personal relevance, the model revealed no significant interaction ($b = -0.10$, 95% CI = $[-0.25, 0.04]$, $p = .16$). Lastly, the interaction between message congruency and subjective knowledge showed a significant negative effect on support ($b = -0.14$, 95% CI = $[-0.24, -0.03]$, $p = .010$).

To further explore the dynamics of message congruency, the *conditional average slopes* for message congruency were assessed at different levels of the moderator variables (low = 1, medium = 4, and high = 7) for the outcomes support and behavioral intentions. As displayed in Figure 32, concerning *support*, the conditional effects estimates for message congruency (with congruent messages as the reference category) indicated that the effect of message congruency on support did not differ significantly across the different message *valence perception* levels. This was evident at the lower level of perceived message valence ($b = -0.37$, 95% CI = $[-1.00, 0.24]$, $p = .23$), as well as at the moderate level of perceived message valence ($b = -0.19$, 95% CI = $[-0.43, 0.05]$, $p = .12$), and at a higher level of the moderator variable ($b = 0.18$, 95% CI = $[-0.09, 0.46]$, $p = .18$).

For support based on the levels of *subjective personal relevance perception* regarding message congruency, as shown in Figure 32, estimates at the low level of subjective personal relevance had no effect on support ($b = 0.15$, 95% CI = $[-0.36, 0.67]$, $p = .55$). This lack of significance was also observed at the medium level of subjective personal relevance ($b = -0.07$, 95% CI = $[-0.30, 0.14]$, $p = .48$) and at the high level of subjective personal relevance ($b = -0.096$, 95% CI = $[-0.34, 0.15]$, $p = .44$), when non-congruent messages were compared to congruent messages (see Figure 32). As shown in Figure 32, at the low level of respondents' *subjective knowledge* (scale point = 1), the

conditional effect of message congruency on support was positive, though this effect was non-significant ($b = 0.31$, 95% CI = $[-0.03, 0.65]$, $p = .074$), suggesting that individuals with low subjective knowledge did not significantly differ in their support for congruent versus non-congruent messages. Concerning the medium level of subjective knowledge (scale point = 4), the estimate was negative, but also non-significant ($b = -0.05$, 95% CI = $[-0.22, 0.11]$, $p = .51$). However, at the high level of subjective knowledge (scale point = 7), the estimate became significant and negative ($b = -0.31$, 95% CI = $[-0.61, -0.00]$, $p = .045$). This finding indicates that for individuals with high subjective knowledge, non-congruent messages (e.g., a loss-frame paired with a positive image) elicited significantly lower support compared to congruent messages (e.g., a gain-frame paired with a positive image). Therefore, the result suggests that people with higher subjective knowledge are less supportive of messages that are incongruent with their expectations or prior knowledge about the technology.

For the mixed model predicting *behavioral intentions* (see Table 16, Model 2), the effect for message congruency did not differ from the reference category of congruent conditions ($b = 0.09$, 95% CI = $[-0.58, 0.75]$, $p = .79$). The interaction between message congruency and perceived message valence yielded no significant interaction effect ($b = 0.14$, 95% CI = $[-0.01, 0.29]$, $p = .068$). These findings are further evidenced by the conditional effects depicted in Figure 32, which reveal that there was no significant influence at the low level of perceived message valence, ($b = 0.082$, 95% CI = $[-0.462, 0.627]$, $p = .76$), which was also visible at the medium level of perceived message valence ($b = 0.044$, 95% CI = $[-0.170, 0.260]$, $p = .68$) and at the high level of perceived message valence ($b = 0.10$, 95% CI = $[-0.137, 0.344]$, $p = .39$).

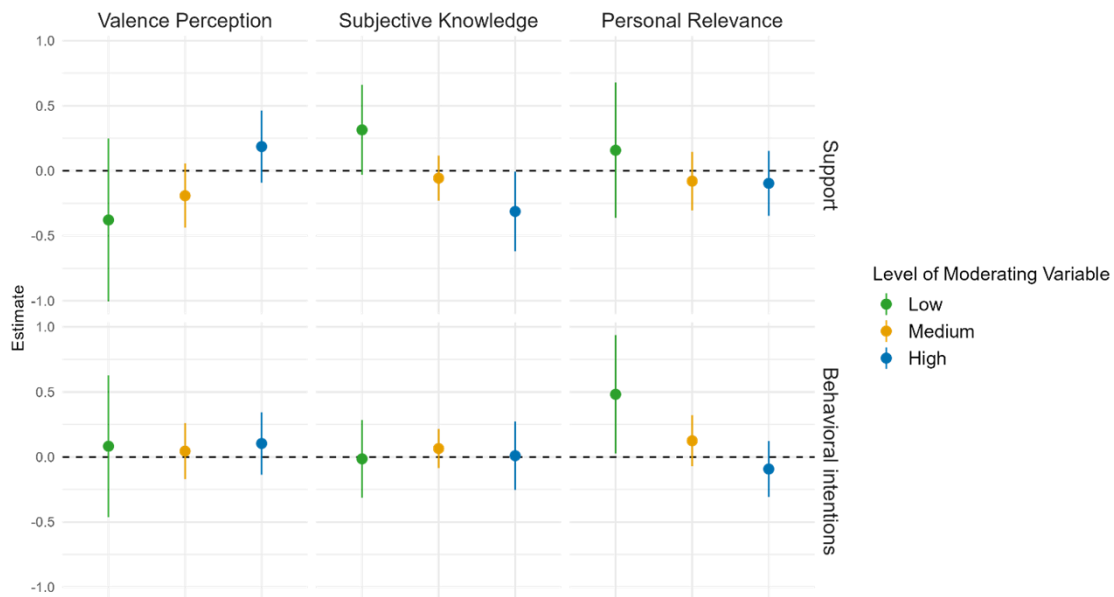
Concerning message congruency and subjective personal relevance perception, a significant negative interaction on behavioral intentions could be detected ($b = -0.18$, 95% CI = $[-0.31, -0.05]$, $p = .006$). As Figure 32 shows, when examining the outcome of behavioral intentions based on the levels of *subjective personal relevance perception* concerning message congruency, it is evident that behavioral intentions are significantly higher at the low level of subjective personal relevance perception for non-congruent messages compared to congruent messages ($b = 0.48$, 95% CI = $[0.02, 0.93]$, $p = .038$). This implies that when individuals perceive a topic as less personally relevant, messages that are not consistent with their expectations or beliefs (non-congruent messages) may be more likely to motivate them to take action or change behavior. However, no effect was detected at the medium level ($b = 0.12$, 95% CI = $[-0.07, 0.32]$, $p = .21$) or at the high

level of subjective personal relevance ($b = -0.09$, 95% CI = $[-0.30, 0.12]$, $p = .39$) on behavioral intentions.

Furthermore, a significant main effect was found for subjective knowledge, indicating that higher levels of knowledge are associated with increased behavioral intentions ($b = 0.15$, 95% CI = $[0.07, 0.22]$, $p < .001$). Concerning behavioral intentions, the conditional effects showed that a low level of *subjective knowledge* had no effect ($b = -0.01$, 95% CI = $[-0.31, 0.28]$, $p = .92$), which was also evident at the medium level of subjective knowledge ($b = 0.06$, 95% CI = $[-0.08, 0.21]$, $p = .39$) and at the high level of subjective knowledge ($b = 0.00$, 95% CI = $[-0.25, 0.27]$, $p = .94$) (see Figure 32), indicating no significant influence on behavioral intentions for non-congruent messages when compared to congruent messages.

In summary regarding *H2.5*, concerning support for emerging technologies, only high levels of subjective knowledge were associated with a decrease in support for non-congruent messages compared to congruent messages. Conversely, a low level of subjective personal relevance perception exhibited a significant positive influence on behavioral intentions, suggesting that lower subjective personal relevance perception was associated with an increase in behavioral intentions for non-congruent messages compared to congruent messages.

Figure 32. Conditional average slopes for the interaction effects between message congruency and moderator variables in predicting support and behavioral intentions toward emerging technologies



$n = 289$, $n = 669$ observations. Conditional average slopes for the effect of message congruency (non-congruent: congruent) across different levels of moderator variables of message valence perception, subjective knowledge, and subjective relevance perception on the outcomes of support and behavioral intentions towards emerging technologies. Each point represents the estimated effect of message congruency at low (=1), medium (=4), and high (=7) levels of the respective moderator, with 95% confidence intervals. The horizontal dashed line at zero indicates no effect.

6.4 Summary and Study Specific Discussion

This study builds upon a paucity of research on the framing of messages pertaining to gains and losses in the context of science communication, particularly with regard to emerging technologies. It also draws upon the visual presentation of message content as evidenced by the valence of pictures to ascertain the influence on attitudes toward these technologies. An examination of the findings indicated that individual differences, or person-level factors, play a significant role in shaping perceptions regarding emerging technologies. In contrast, technology-level differences applied in newspaper articles appeared to exert a comparatively lesser influence on these perceptions. Furthermore, interaction effects regarding message framing and message framing congruency have been identified and will be discussed in the following sections.

Person-level and technology-level differences

In exploring *RQ2.1*, two intercept-only mixed models were utilized in study 2 to assess support and behavioral intentions toward emerging technologies, focusing on random intercepts for participants and technology stimuli. Notably, the analysis revealed significant individual variability in both support and behavioral intentions, underscoring the pivotal role that personal differences play in shaping attitudes toward emerging technologies. While participant differences accounted for a substantial portion of the variance, the specific technology stimuli had a minimal impact. Consequently, it can be deduced that factors external to the technology in question play a substantial role in determining support and behavioral intentions. Moreover, the findings underscored the necessity for more comprehensive models that encompass additional variables affecting attitudes toward emerging technologies. To elucidate this point, the experimental factors of message framing and picture valence were examined.

Message framing and message congruency effects

In order to investigate the influence of message framing, the gains or losses associated with the application of these technologies to shape audience attitudes were given emphasis (*RQ2.2*). Studies conducted previously on the subject of goal message framing (R. W. Rogers, 1983; Tannenbaum et al., 2015), have yielded findings that are consistent with the present results. Specifically, the findings indicated that loss framing, that is, the highlighting of unfavorable consequences that may result from the non-adoption of emerging technologies, tends to be an effective strategy for influencing support toward such technologies. The observed phenomenon can be attributed to a negativity bias, which posits that negative information exerts a more substantial influence on attitudes in comparison to neutral information (Meyerowitz & Chaiken, 1987; Seo et al., 2013). Notably, the positive message framing employed in the text did not exert a significant influence on attitudes, thereby leaving unresolved the question of whether a more specific attribute framing (Levin et al., 1998) that accentuates particular benefits or harms of the technology could elicit more pronounced shifts in attitudes.

To address question *RQ2.3*, the subsequent step involved an evaluation of the effect of picture valence. However, the results indicated that picture valence itself did not emerge as a significant factor. It has been demonstrated that visual media is typically processed more rapidly and can exert a more substantial influence than written text (Geise & Baden, 2015). Moreover, the present study offers substantiation that the integration of

visual elements can augment the efficacy of text-based framing. Specifically, the confirmation of *H2.1* partially congruent framing — where both the text and images had a positive valence — resulted in greater support for emerging technologies. However, this effect was only observed in the case of gain-framed text paired with positive imagery, as compared to a control condition with neutral framing. Consequently, these findings imply that the integration of visuals can augment the persuasive efficacy of gain-framed messages, a notion that is consistent with the findings of previous studies (J. Lee & Cho, 2022; Seo & Dillard, 2019). Nevertheless, the study revealed no significant differences when comparing congruent (e.g., positive text and images) to non-congruent framing (e.g., positive text and negative images). It can be concluded that the absence of significant differences between congruency conditions can be attributed to several factors related to how individuals process information and the psychological mechanisms involved.

Moderators of message congruency effects

Furthermore, the present study demonstrated the significant impact of moderating variables, namely subjective knowledge and subjective personal relevance perception, in shaping both support for and behavioral intentions toward emerging technologies (*H2.5*). The incorporation of interaction effects between message congruency and these individual variables resulted in a 32% increase in explained variance for support and, respectively, a 36% increase for behavioral intentions. Higher levels of knowledge, as indicated by the findings, are associated with greater alignment between text and visuals, as evidenced by the persuasion theory. This is particularly pronounced in cases where the text and visuals are not aligned, suggesting a reduced propensity for non-congruent messages compared to congruent messages. According to the Elaboration Likelihood Model (ELM), knowledgeable individuals engage in deeper, central route processing, critically assessing message quality (Petty & Cacioppo, 1986a, 1986a).

Inconsistency between text and visuals can lead to a negative evaluation of the issue. Conversely, congruent messages have been shown to be more readily aligned with critical processing, thereby enhancing support (Chaiken & Maheswaran, 1994; Lavine & Snyder, 1996). In a similar vein, non-congruent messages have been shown to create a mismatch with the established beliefs of knowledgeable individuals, leading to discomfort and reduced message effectiveness (Petty & Wegener, 1998b). When there is consistency in the messages conveyed, it helps to mitigate this discord, thereby fostering a more robust level of support (Festinger, 1957; Sherman & Gorkin, 1980). Consequently,

individuals with higher levels of knowledge are more likely to reject messages that are incongruent with their pre-existing beliefs, as such messages conflict with their understanding. Conversely, messages that align with their beliefs are more likely to be accepted and can reinforce their existing attitudes, leading to greater support (Kunda, 1990).

Additionally, this study's findings complement the existing body of research by demonstrating that lower personal relevance can enhance the efficacy of non-congruent messages in promoting behavioral intentions. In circumstances where a topic is deemed less personally relevant, individuals may engage in a more superficial or heuristic processing of the message. In such cases, there is a reduced probability of an examination of discrepancies between the message and its accompanying visual content (Chang, 2002). In accordance with information processing theories, when individuals perceive a message to be of minimal personal relevance, they are more inclined to rely on peripheral cues, such as visuals or the tone of the message, rather than engaging in thorough processing of its content (Petty & Cacioppo, 1986a). It is also plausible that individuals may resolve the incongruity between non-congruent messages and visuals by adjusting their behavioral intentions in a systematic processing way that reduces internal conflict, even if the topic is of lower relevance (Maheswaran & Chaiken, 1991).

Implications and limitations

However, it is imperative to acknowledge the limitations of generalizing the observed effects, as they may be contingent upon the specific context of the technology issues under study. The statistical model incorporated variability in attitude formation across the five technology issues, and descriptive analyses indicated that technologies, such as personalized medicine, which are more readily tangible in respondents' daily lives, received higher levels of support and behavioral intentions. However, the study was primarily designed to test equivalence framing and did not address the interaction between technology issues. In this regard, further investigation of additional technologies and a comprehensive review of gain and loss framing effects will shed more light on the impact on attitude formation.

That said, it must be acknowledged, however, that the present study is not without its limitations with respect to the measurement of intervening variables. One should note that the study exclusively measured subjective and self-rated knowledge levels of the participants. Conversely, objective or factual knowledge about the issues under study, as suggested by other authors (e.g., S. Lee et al., 2021), was not assessed. Furthermore, the

extent of knowledge regarding the issue under consideration can function as a processing variable over time. Individuals with limited knowledge appear to demonstrate immediate framing effects, while those with greater knowledge and higher motivation to process the information are more likely to exhibit resistance to persuasion and still show effects (Lecheler & De Vreese, 2011). A longitudinal study design that measures various aspects of knowledge would benefit future research.

Additionally, other variables related to science and technology, such as emotional responses (e.g., fear), may play a mediating role in the relationship between verbal and visual communication and attitudes (Nabi et al., 2019; Seo & Dillard, 2019). For example, benefit and risk narratives, such as those related to nanotechnology (Lewenstein et al., 2005) have been demonstrated to be correlated with other attitude variables, including technology risk evaluations (Nisbet & Mooney, 2007). Visual images have been demonstrated to elicit specific emotional responses, such as sympathy, fear, or anger. Such responses shape how individuals interpret events and the policies or actions they support or refute (Iyer et al., 2014). To this end, emotional reactions serve as the driving force that prompts individuals to adopt particular attitudes and intentions. In this regard, the emotional impact of images assumes a pivotal role in the transformation of visual information into meaningful responses. In addition, the interaction effects examined were based on message congruency and individual variables. Consequently, the impact of the text-alone conditions was not investigated. As previously demonstrated, the framing effects for the text-alone condition may be evident among participants with extensive issue-specific knowledge (Powell et al., 2015).

Moreover, the study's sample size was restricted to a single online service provider, which may limit the generalizability of its findings. The procedure described herein has been demonstrated to facilitate the recruitment of respondents exhibiting greater demographic diversity, including variations in age, in comparison with alternative data sources such as university pools. Furthermore, it has been shown to be comparable and reliable to the extent that it holds up to the standards set by other established data sources (Behrend et al., 2011). Nevertheless, it is important to note that the findings of this study cannot be generalized to the British public as a whole. Therefore, it would be beneficial to conduct further research in different national contexts.

Finally, the study's findings offer implications for the field of science journalism. Specifically, the study supports the notion that newspapers can enhance the presentation of scientific content by incorporating visual aids that reinforce textual arguments

regarding technology's potential consequences (Messaris & Abraham, 2001). Visuals reflecting a positive tone have been shown to increase reader interest and encourage them to engage with topics, potentially influencing their support for political actions such as funding for innovative energies. In this context, the framing of the message and the credibility of the media outlet or communicator are both crucial factors in shaping perceptions of message trustworthiness (Lindgren et al., 2022). Single-channel messages require the least processing capacity in comparison to messages stemming from multiple channels, especially those with conflicting messages (Lang, 1995). It is imperative that future research investigates the effectiveness of framing in different formats, such as image-only versus image-plus-text conditions. Information processing and relevant variables such as recognition and recall may differ across various media types. Thus, the need for comparative studies on congruency framing in more dynamic formats, such as video or audio, is suggested, especially in the context of science and technology communication.

Conclusion

In summary, this study provides valuable insights into the complex interplay of message and individual factors that shape recipients' attitudes toward emerging technologies. Given the considerable variability in support and behavioral intentions, it is evident that personal differences play a critical role in shaping these attitudes. While technological stimuli exerted a certain influence, individual perceptions and characteristics proved to be more substantial factors, thus necessitating more comprehensive explanation models that integrate various factors, including message framing, congruency with visual presentation, and participants' prior attitudes.

The findings underscore the efficacy of loss framing in modulating attitudes toward technology, a phenomenon potentially influenced by the negativity bias. In essence, this suggests that accentuating the repercussions of a passive stance may prove more compelling to audiences than the employment of a positive framing strategy in isolation. Furthermore, the study demonstrates that visuals can enhance the effectiveness of gain-framed messages, emphasizing the need for congruency between text and imagery to maximize persuasive outcomes. Of particular significance were the moderating effects of subjective knowledge and subjective personal relevance perception, which illustrate that individual perceptions significantly shape responses to message framing. Hence, it was demonstrated that knowledgeable individuals engage more critically with messages, leading to heightened sensitivity to incongruency. Conversely, lower personal relevance

perception may allow for greater flexibility in processing non-congruent messages, potentially leading to increased engagement (Chaiken & Maheswaran, 1994; Chang, 2002).

Despite its contributions, the study has limitations concerning the context-specific nature of the findings. Future research should expand the exploration of different framing formats and the role of emotional responses, while considering the broader implications for science journalism. In the context of newspaper articles, the credibility of the source from which information is derived can exert a profound influence on the persuasive outcomes of the message conveyed (Frewer et al., 1997; Manca et al., 2019). Audiences tend to exhibit a heightened propensity to place their trust in information presented by sources that are recognized as reputable or familiar, thereby amplifying the effectiveness of the communicated message. To that end, enhancing the presentation of scientific content through effective framing and trustworthy sources is essential for fostering public understanding and acceptance of emerging technologies. The present study underscores the necessity for continued research into the nuances of media framing and its effects on attitudes, particularly in an era of rapid technological advancement. It is imperative to comprehend these dynamics to develop effective communication strategies that engage diverse audiences and promote informed decision-making regarding emerging technologies.

7. Study 3: Source Credibility Effects

The third experimental investigation was dedicated to source effects of newspaper articles to influence recipients' credibility perceptions and addressed the role of scientist presentation as a source in newspaper articles, which is outlined in the subchapters concerning research questions and hypotheses (7.1), methods (7.2), results (7.3), and a summary and discussion of findings (7.4).

7.1 Research Questions and Hypotheses

Source credibility - or the attitude a message receiver holds toward the source of communication - has been identified as a salient variable in persuasive communications (Chaiken & Maheswaran, 1994; McCroskey & Young, 1981; Pornpitakpan, 2004). The cognitive perspective on persuasion (Chaiken, 1980; Meyerowitz & Chaiken, 1987; Petty & Cacioppo, 1986a) posits that source variables assume divergent roles, contingent upon the extent of personal involvement. In circumstances characterized by minimal personal engagement, individuals have been observed to predominantly employ heuristic (Chaiken, 1980; Chaiken & Maheswaran, 1994) or peripheral route (Petty & Cacioppo, 1986a) processing strategies. In such situations, individuals utilize source characteristics such as expertise, likeability, or attractiveness to assess message validity, rather than focusing on the message content itself (e.g., Petty et al., 1981). This approach to persuasion emphasizes cognitive economy, leading recipients to concur more with an expert or a likable source regardless of argument strength (DeBono & Harnish, 1988). In contrast, high personal involvement prompts systematic (Chaiken, 1980), or central route processing (Petty & Cacioppo, 1986a), driven by an increased need to understand the message's content. Under these conditions, recipients focus on the strength and cogency of the arguments presented, with source variables exerting little to no direct influence on persuasion. Consequently, source credibility exhibits an interactive relationship with specific conditions pertaining to the source, message, channel, receiver, and destination variables (Chaiken, 1980; Puckett et al., 1983).

In circumstances where the credibility of scientific sources is threatened and scientific authority and expertise are questioned (see, for example Howell et al., 2020; Weingart, 2023), the public image of scientists reflects dimensions of trust and distrust, as well as the perception of progress and threats to science and technology (e.g. Renn & Levinde, 1991; Weingart, 1999). Media reporting portrayals of scientists have been identified as a contributing factor to the public's perception of science and scientists (Steinke,

2005). Stereotypes, such as the depiction of scientists as elderly males working in a laboratory, are cultivated through media portrayals (Mead & Métraux, 1957). These stereotypes have been debunked by studies that have shown that children's drawings of scientists are more accurate when scientists are depicted with scientific equipment (e.g., Chambers, 1983; Rubin et al., 2003).

The influence of person-level and topic-level differences

As indicated in previous research, individual differences in science communication audiences, including the role of demographics and prior attitudes, have been identified as salient factors (Brossard & Nisbet, 2007; Ho et al., 2008; C. Lee & Scheufele, 2006). Furthermore, technology-related topics are associated with varying levels of knowledge and attitudes (see chapter 5 on contextual determinants). Consequently, this study explores the impact of these two factors on credibility perceptions:

RQ3.1: Which factor contributes more to the explanation of message credibility and source credibility, differences at the level of persons or at the level of technology topics of newspaper stimuli?

Influence of scientists' gender as a source

Although the impact of scientists' gender as a source of influence has been examined in various contexts (Flanagin & Metzger, 2003; Goldberg, 1968; Pearson, 1982), more systematic research on gender as a source variable is needed (Pornpitakpan, 2004). However, the available literature on source credibility perceptions by gender of the source has also been considered inconclusive and contingent on the dimension under investigation (Miller, J., D. & McReynolds, 1973). On the one hand, evidence suggests that when all other source qualifications and message content are held constant, receivers tend to rate a male communicator as more competent than a female communicator. This is because an "authoritative expert" is stereotypically associated with masculinity (Miller, J., D. & McReynolds, 1973). On the other hand, women can be perceived as more trustworthy or expressing more warmth (Eagly & Mladinic, 1994; Widgery, 1974). As Pearson (1982) discussed, the attribution of credibility to gender is determined by processing information on the source as scientists, whether male or female, prior to reading a news article. This phenomenon is referred to as intrinsic credibility. Alternatively, impressions are shaped

secondarily, in response to the gender of the message (extrinsic credibility) (see also Miller, J., D. & McReynolds, 1973).

One implication of this is that source cues of gender may out level cues of expertise, as they activate gender stereotypes and biases. Whether female scientists might violate congruency norms of male scientists has been a subject of debate (Dasgupta & Asgari, 2004). The accessibility of stereotypes influences the processing of new information in accordance with existing stereotypes and schemas (Fiske & Taylor, 2017). According to the Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986), implicit gender stereotypes may influence perceptions of message credibility and communicator credibility via the peripheral route. For instance, if readers are only able to rely on the author's name and lack other cues regarding the author's credibility, they may rely on gender stereotypes (Deaux & Lewis, 1984).

A body of experimental research has indicated that there are differences in the evaluation of expert credibility based on gender. Specifically, news items read by female newscasters were perceived as more credible, whereas male newscasters were considered to be more credible persons (Weibel et al., 2008). Furthermore, male political experts were found to be more credible than female ones (Ozer, 2023), and statements attributed to a female scientist, were rated as significantly more dramatic and biased by male scientists than by their female counterparts (Armstrong & Adamson, 2021). However, other studies did not find clear gender biases in individuals' expert evaluations (Greve-Poulsen et al., 2021; Paul et al., 2022; Yeo et al., 2022). Reflecting on theoretical and empirical implications on gender as source cue, it becomes evident that no specific gender can be attributed as higher in perceived credibility of the message or scientist as communicator. Therefore, for the science communication context of this study the following research question is proposed:

RQ3.2. To what extent does the gender of scientists (male or female) influence participants' perceptions of message credibility and source credibility?

Audience's gender as intervening factor

Moreover, the gender of the source has been observed to interact with the gender of the respondents in terms of attitude change and credibility ratings (Goldberg, 1968). Specifically, the gender of the audience can significantly affect their perceptions of the source, leading to what is known as the gender affinity effect (see for example Dolan, 2008). According to this effect, participants exhibit a preference for communicators of their own gender. This phenomenon has been observed in various contexts, including voting behavior (Fulton, 2014) and evaluations of newspaper columnists (H. A. White & Andsager, 1991). In educational settings, the influence of gender on perceptions of scientists has been extensively documented. Research has revealed that female students exhibit higher ratings for female scientists when exposed to counter-stereotypic images compared to stereotypic images of male scientists. Conversely, male students exhibited a higher rating for male scientists after viewing stereotypic images than after seeing counter-stereotypic images (Good et al., 2010). However, contrasting findings have also emerged, indicating that the credibility of the opposite gender may sometimes be rated higher (Flanagin & Metzger, 2003). These findings underscore the importance of the context in which source-participant interactions occur, suggesting that the perceived credibility of scientists in a newspaper context may vary depending on the demographic characteristics of participants. Therefore, understanding these dynamics leads to the following research question:

RQ3.3. How does the gender of participants interact with scientist's gender, age, and the presence of a picture to influence participants' perceptions of message credibility and source credibility?

Age of the Scientist

The age of the source of communication has been identified as a salient factor in media portrayals, particularly photographs, influencing how individuals are perceived based on respective evaluations (Edström, 2018). Research suggests that age can activate both positive and negative schemata, leading to the formation of implicit stereotypes (D. L. Hamilton & Sherman, 1994). Negative stereotypes associated with age may include perceptions of lower qualifications and reduced potential for development in the case of older age of an individual, which can predict intentions toward discriminatory behavior, especially in professional contexts (Chiu et al., 2001; Kite & Johnson, 1988). In contrast, older individuals are often perceived as more experienced, reliable, and knowledgeable

(Finkelstein et al., 2000). However, the impact of age on perceptions of expertise remains inconsistent across studies, with some findings indicating no significant relationship between age and how individuals are stereotypically judged (Puckett et al., 1983).

In the context of science communication, the dimension of expertise is closely associated with the professional status of scientists, where age functions as a peripheral cue within the framework of persuasion theory (Chaiken, 1980; Petty & Cacioppo, 1986a). This phenomenon is manifest in the prevailing perception that senior scientists are regarded as the most reliable sources of scientific information (Weibel et al., 2008). As such, the persuasiveness of a message is influenced by peripheral cues, such as the age of the communicator, which can affect audience attitudes and beliefs (Chaiken, 1980; Petty & Cacioppo, 1986a). Older individuals are perceived as more trustworthy, thereby lending credibility to their messages and enhancing the persuasive power of their communications (McCroskey, 1966). In summary, the influence of age stereotypes on audience perceptions can be outlined as follows:

H3.1: Older age in scientists is positively associated with message credibility and source credibility.

Picture of the scientist

As previously mentioned, the credibility of a scientist's image, particularly with regard to factors such as age and gender, is significantly influenced by societal perceptions and stereotypes. In this regard, age is frequently regarded as a pivotal indicator of expertise, with older scientists often being perceived as more experienced and knowledgeable. Such a perception can be attributed to a societal belief that associates age with wisdom (Finkelstein et al., 2000). The credibility of a scientist is enhanced in fields that value established knowledge and a lengthy track record due to this perception. Research on gender representation as a key factor influencing perceptions of credibility indicated that male scientists, particularly in traditionally male-dominated fields like engineering or physics, are often viewed as more authoritative and competent due to existing biases (Knobloch-Westrick et al., 2013). Conversely, female scientists can enhance their credibility by challenging these stereotypes, especially when they are perceived as warm and approachable (Jarreau, 2015).

Visual congruency has been identified as a critical factor in determining credibility. The utilization of images that align with the demographic characteristics of scientists,

such as age and gender, in conjunction with the subject matter of their research, has been demonstrated to augment the persuasive efficacy of scientific communication (Gheorghiu et al., 2017). To illustrate, the image of an older male scientist discussing well-established scientific principles can elicit a sense of credibility. Furthermore, the employment of visual representations of scientists in professional environments, such as laboratories or academic settings, has been demonstrated to augment their perceived credibility (Evagorou et al., 2015). This is attributed to the provision of context that aligns with audience expectations regarding scientific endeavors. In the context of persuasion theory, the efficacy of visual cues indicates that individuals frequently process visuals as peripheral cues, influencing attitudes and perceptions without necessitating extensive cognitive processing (Chaiken, 1980; Petty & Cacioppo, 1986a). Consequently, visuals can promptly influence audience perceptions regarding a scientist's credibility, often bypassing more rigorous assessments of the underlying research quality in the message. Therefore, it can be concluded that a designed image of a scientist that aligns with their age, gender, and research focus can significantly enhance the persuasive effect of communication, leading to more positive attitudes and greater acceptance of the scientist's work:

H3.2. The presence of a picture of the scientist in the newspaper article positively influences message credibility and source credibility.

The influence of prior attitudes

Furthermore, the credibility of the communicator is most effective when the receivers of information have limited accessible information and attitudes regarding the message content (see for example Chaiken & Maheswaran, 1994). In circumstances where recipients lack established attitudes regarding the subject matter, they are more inclined to place greater reliance on the credibility of the source in forming their judgments (Kumkale et al., 2010). Research indicates that when the *personal relevance perception* of an issue is low, a highly credible source tends to be more persuasive than a low-credibility source. In such cases, cues such as visual representations and the source's perceived expertise play a more significant role than the actual message content (McGuire, 1985b; Petty et al., 1981).

In this context, prior attitudes significantly influence the processing of source cues and credibility perceptions. *Subjective knowledge*, defined as an individual's self-assessment of their understanding of a given topic, has been demonstrated to affect how they

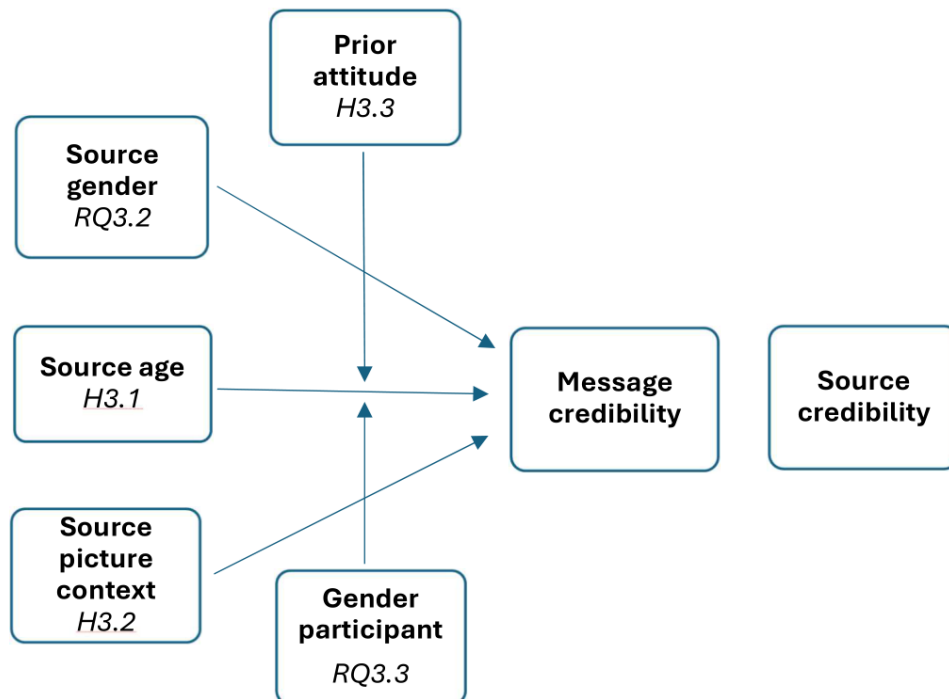
evaluate the credibility of the source. Research findings indicated that individuals with limited subjective knowledge or less stable attitude of a subject are more likely to accept the communicator's authority and expertise, thereby amplifying the source's persuasive impact. Conversely, individuals with higher subjective knowledge may engage in more critical scrutiny of the message, potentially undermining the communicator's credibility, even if they are perceived as credible (Tormala & Petty, 2004). The role of message content *support* in moderating the relationship between source credibility and attitude change is also of crucial importance. When audiences perceive a source as credible, they are more likely to align their attitudes and behaviors with the message, particularly if they already have a predisposition toward the topic (Chaiken, 1980; Petty & Cacioppo, 1986a). However, when the level of support for the message is low, even a credible source may encounter difficulties in persuading the audience (Tormala et al., 2006). Furthermore, behavioral intentions have the capacity to influence the perception of source credibility. In situations where the audience exhibits a neutral or uninformed stance regarding the subject, high-credibility sources have been found to be more effective in promoting positive behavioral intentions. In contrast, when individuals possess strong prior attitudes or knowledge about the subject, their behavioral intentions may be less susceptible to influence from the source's credibility (Yuan et al., 2019). This finding suggests the existence of a moderating effect, whereby subjective knowledge, subjective relevance perception, support for the message, and behavioral intentions act as factors that influence the relationship between source cues and credibility perceptions. Consequently, the following postulate is advanced:

H3.3: The source effect of the scientist's gender, age, and picture on credibility perceptions is expected to be more pronounced under conditions of lower prior attitudes (subjective knowledge of the technology, subjective personal relevance perception, issue support, behavioral intentions towards the issue) regarding the perceived message credibility and source credibility.

Overall, the impact of scientists' demographic characteristics on their credibility when presented in newspapers is of interest in study 3. The first step (*RQ3.1*) investigates whether person-level or topic-level differences are more influential in credibility perceptions. Furthermore, as shown in Figure 33, the indication of scientists' gender (*RQ3.2*) and age (*H3.1*), as well as the visual presentation of the source (*H3.2*) in the newspaper

articles, are investigated for their influence on message and source credibility perceptions. A possible gender affinity effect is also examined (*RQ3.3*). Finally, the moderating influence of prior issue attitudes on the effect of source characteristics on credibility perceptions (*H3.3*) is tested.

Figure 33. Overview on determinants and outcomes regarding the research questions and hypotheses for study 3



7.2 Methods

This section offers a synopsis of the methodologies employed in study 3 on source credibility effects, while providing a detailed overview of the experimental design (7.2.1), experimental manipulation (7.2.2), the online questionnaire procedure and measures (7.2.3), the study's sample and power analysis (7.2.4), and the data analysis techniques utilized (7.2.5).

7.2.1 Experimental Design

In the third empirical investigation, the three experimental factors of *gender*, *age*, and *picture of the source* were assessed in terms of their impact on *message credibility* and

source credibility perceptions. Using an experimental approach ensured causal inference, minimized confounding variables, and allowed for a nuanced understanding of the interaction effects between these variables (Shadish, 2001), which was essential for addressing the research questions and hypotheses about the effects of source characteristics on credibility perceptions.

Study 3 was realized in using a mixed design with three-between-subjects factors: *2 gender of scientist (male/female) x 2 age (young /old) x 2 picture of the scientist (picture/no picture)*. The three factors of gender of the scientist, age of the scientist, as well as the presence of a picture were fully crossed factors in the research design. Every respondent read articles with randomized combinations of gender and age of scientists in text and pictures, resulting in eight conditions of these experimental factor combinations. This was achieved by presenting the gender and age of the scientist along with their statements on technology-related topics in the newspaper articles, which were optionally accompanied by a picture of a scientist based on the combination of age and gender in the text. Furthermore, participants could be assigned to a control condition that was not crossed with the other factors. This condition indicated no indication of scientists' gender and age and no picture alongside the article. Therefore, the total number of possible conditions was nine, encompassing scientists' gender, age, and the presence of a picture. Additionally, as in study 2, a 5-level within-subjects factor was employed for the technology topic, addressing issues related to *biofuels, electric vehicles, personalized medicine, functionally graded materials, and precision agriculture*. As implied by Table 19, participants were exposed in random order to each technology topic. This experimental factor was not fully crossed like the factors of scientists' gender, age and picture. Instead, participants were exposed to one random combination of the source factors across the five technology stimuli. Thus, this design had 45 conditions (9 between-subjects conditions $\times$ 5 within-subjects topics), resulting in $n = 3,245$ observations from $N = 649$ participants.

Table 19. Example of the data structure for the third study relating to source effects

Partici- pant	Technology Issue	Gender Scientist	Age Scientist	Picture Scientist	Scientist' Credibility
1	Biofuels	Male	Old	Yes	5.2
1	Electric vehicles	Female	Young	No	4.7
1	Personalized medicine	Male	Old	No	4.8
1	Functionally graded materials	Neutral	-	-	4.3
1	Precision agriculture	Female	Old	No	4.1
2	Biofuels	Male	Old	No	5.7
2	Electric vehicles	Male	Young	Yes	6.4
2	Personalized medicine	Male	Old	No	3.5
2	Functionally graded materials	Female	Young	Yes	5.8
2	Precision agriculture	Neutral	-	-	4.6

The response score provided for the outcome variable of scientist' credibility shows exemplary measures for two participants over the stimuli of technology issues crossed with the experimental manipulation of gender of the scientist, age of the scientist, and presence of a picture. Additionally, the control condition was not a crossed factor and displayed a gender-neutral name and no age or picture manipulation.

7.2.2 Experimental Manipulation

For the third study, the five technologies of personalized medicine, electric vehicles, biofuels, precision agriculture, and functionally graded materials were employed as issues for the newspaper stimuli. To detect the effect of scientists' gender in newspaper articles, the gender of the communicator was manipulated in the text by mentioning a popular English female or male first name relating to the scientist. The factor of age was accounted for by mentioning the age of the scientist accompanying their name after the statement they had made in the newspaper article, for example, "says Dr. Peter Smith, a 32-year-old researcher." In this manner, the age of the scientist was represented as ranging from 30 to 35 years in the articles for younger age groups and from 60 to 65 years for older age groups. To ensure external validity, the newspaper stimuli were developed based on actual news articles with minor amendments and reductions in the length of text, but with no specific layout of a newspaper outlet. Regardless of the topic, the length of

the message was kept constant. Moreover, the newspaper articles discussed technology issues in an informational tone, while the scientists were associated with different affiliations by US university departments of middle ranking universities in the Shanghai University Ranking (Shanghai Ranking, 2024). Therein, the scientists were introduced as researchers or authors of the study or research reported on in the text, which provided statements to the technology topics.

In order to detect the additional effect of the visual presentation of scientists, pictures of the scientists were embedded in the newspaper texts according to their allocation of gender and age mentioned in text. These images were generated by the text-to-image generator from Stable Diffusion XL (2023), as the tool's X/Y/Z plot function enabled the manipulation of age and gender attributes through textual prompts. To achieve this objective, images were generated in which the subjects appeared to be within the specified age ranges. For this purpose, the text prompts employed in Stable Diffusion were of the same seed, and the images were created for scientists aged 30 and 60 years, as well as for both female and male subjects. This approach was adopted to ensure uniformity in the depiction of scientists across different age and gender groups. To this end, scientists within each gender and age pair were positioned in a manner that ensured close resemblance in terms of camera angle and the presence of portrait pictures with similar facial expressions and backgrounds.

A total of 20 combinations of four portrait pictures of scientists were created, encompassing scientists of varying genders and ages. To ensure the validity of the experimental manipulation, these picture collages were pretested in undergraduate student classes at Johannes Gutenberg University-Mainz ($N = 23$). During the pretest, the participants were asked to evaluate the realism of the pictures in terms of their representation of a scientist ("The persons shown in the pictures are a realistic representation of a scientist", 10-point-scale: 1 = strongly disagree to 10 = strongly agree). The picture collages that received the highest mean ratings for their realistic depiction of a scientist were selected for the newspaper articles of the main study, which were to be applied to each technology issue in the newspaper articles (see [online appendix](#)). Prior to data collection, two individuals conducted pretests to determine that the survey would take between 10 and 15 minutes to complete. As indicated by Figure 34, of a newspaper article addressing the biofuels issue, the text incorporates the gender and age of the scientist, accompanied by an image of a female scientist of considerable seniority.

Figure 34. Stimulimaterial newspaper condition for study 3

The Coming Of Biofuels: Study Shows Reducing Gasoline Emissions Will Benefit Human Health

When it comes to transportation fuels, carbon-neutral biofuels as an alternative to gasoline are coming. While the focus of a shift from gasoline to biofuels has been on global warming, such a shift could also impact human health.

The novel and comprehensive “Life Cycle Impact Assessment” measures the benefits on human health that might result from a switch to biofuels. The early results of a new study by a research team of the University of Illinois show that a biofuel eliminating even 10-percent of current gasoline pollutant emissions would have a substantial impact on human health in this country, especially in urban areas.

“In a typical LCIA, we evaluate the potential impact on human health and the environment of a product or activity holistically, by analyzing those effects over the entire life cycle of the product or activity”, says Dr. Linda Smith (a 62-year-old researcher).



“For biofuels, we will ultimately need to look at the overall human health and environmental impacts of biomass production, converting and processing this biomass into fuel, storing, transporting and distributing that fuel, and finally the actual combustion and use of the biofuel. But clearly impacts on human health should be a prime consideration in future fuel policy decisions.”

Newspaper condition showing a scientist of female gender, older age and paired with a picture for the issue of biofuels.

7.2.3 Procedure and Measures

After agreeing to participate in the study, respondents provided sociodemographic information about their gender, age, and education level in the online questionnaire. Participants then rated their prior attitudes toward the technology issues. Then, the newspaper articles for each of the five technology topics were presented to the participants, who, after reading the articles, answered items related to the dependent variables of message credibility and source credibility.

Message credibility

To measure *message credibility* five items were adopted from the news credibility scale by Gaziano and McGrath (1986) and Meyer (1988). Therefore, respondents were asked to rate the credibility of the newspaper article by indicating their perception of the article on 7-point semantic differentials, such as "This newspaper article is biased/unbiased". Table 20 provides a summary of the statistics for the measures used in study 3. Participants' perceptions of *message credibility* were $M = 4.70$, $SD = 1.20$ on a 7-point scale. McDonald's Omega (ω) indicated high internal consistency, both within individuals ($\omega_{\text{within}} = 0.75$) and between individuals ($\omega_{\text{between}} = 0.96$). The ICCs for message credibility showed moderate variability at the person level ($ICC = 0.58$), but little variability at the technology newspaper stimulus level ($ICC = 0.04$), confirming that there was not much additional variance introduced by the technology grouping.

Message evaluation

To distract from the aim of the investigation, two items in the same item battery as the message credibility items were used, asking for general evaluations of the newspaper article, such as "This newspaper article is unreadable/readable". The general message rating showed moderate agreement across participants ($M = 4.93$, $SD = 1.41$), with moderate variability at the person level ($ICC = 0.52$) and low variability at the technology stimulus level ($ICC = 0.09$). Within-person reliability was moderate ($\omega_{\text{within}} = .65$), whereas between-person reliability was high ($\omega_{\text{between}} = 0.92$).

Source credibility (Scientist credibility)

To measure the credibility of the scientist's as communicators, a scale proposed by Ohanian (1990) was used in this study, which is based on three main dimensions of source credibility: trustworthiness, expertise, and attractiveness (see also chapter 3.2.2). More applicable to the context of science news reporting in this study, the credibility of news reporters in the context of gender was assessed by Paul et al. (2022) by asking the extent to which journalists are perceived as expert and trustworthy. To assess the credibility of scientists for this research, eight items from both Ohanian (1990) and Paul et al. (2020) were used, four each for the dimensions of trustworthiness and expertise. The credibility scale used 7-point measures by asking respondents to provide attributes of the scientists in the form of semantic differentials (e.g., "The scientist in the article is dishonest/honest"). Regarding perceptions of source credibility ($M = 4.92$, $SD = 1.18$), the reliability

of this measure was highly consistent between individuals ($\omega_{\text{between}}=.99$) and within individuals ($\omega_{\text{within}}=.85$). The ICCs for source credibility showed more variability at the person level ($ICC = 0.60$) than at the level of the technology newspaper stimuli ($ICC = 0.05$).

Scientist evaluation

In addition, two other items about the scientists' personal traits were used to distract from the aim of the study (e.g., "The scientist in the article is unsympathetic - sympathetic"). The general evaluation of the scientists showed moderate ratings ($M = 4.82$, $SD = 1.23$), with medium variability at the person level ($ICC = 0.55$) and low variability at the level of the technology stimuli ($ICC = 0.05$). Within-person reliability was moderate ($\omega_{\text{within}}=.52$), while between-person reliability was high ($\omega_{\text{between}} = 0.97$).

Support towards emerging technologies

Participants' *support towards emerging technologies* was assessed by using two items which were adapted from C. Lee and Scheufele (2006) and Brossard and Nisbet (2007) (for example "There should be more federal funding for biofuels.") on a 7-point- scale, ranging from 1 = strongly disagree to 7 = strongly agree. Support towards emerging technologies could be considered moderate in the sample ($M = 4.23$, $SD = 1.74$) (7-point scale). McDonald's Omega (ω) indicated high reliability, both at the within-individual level ($\omega_{\text{within}}=.86$) and at the between-individual level ($\omega_{\text{between}}=.98$). As shown by the ICC values, the variability was moderate at the person level ($ICC = 0.45$) and low at the technology level ($ICC = 0.12$).

Behavioral intentions towards emerging technologies

Concerning *behavioral intentions* four items (7-point scale) were adopted from C. Lee and Scheufele (2006). Participants reported a medium score ($M = 3.72$, $SD = 1.74$), with medium variability at the person level ($ICC = 0.55$) and low variability at the technology level ($ICC = 0.08$). Both within-person reliability ($\omega_{\text{within}}=.87$) and between-person reliability ($\omega_{\text{between}}=.97$) were high for behavioral intentions.

Subjective relevance perception of emerging technologies

Three items based on Whitmarsh and O'Neill (2010) were used to measure the subjective relevance perception of emerging technologies. On average ($M = 3.84$, $SD = 1.83$), the

technology topics were perceived as moderately relevant by the participants ($ICC_{\text{person}} = 0.47$, $ICC_{\text{tech}} = 0.13$). The construct of subjective relevance perception was highly reliable at both the between-person level ($\omega_{\text{between}} = .91$) and the within-person level ($\omega_{\text{within}} = .98$).

Subjective knowledge of emerging technologies

Conversely to study 1 and study 2, one item was employed to measure the self-reported *subjective knowledge* of the technology issues (European Commission, 2013; Yang et al., 2017) on a 7-point-scale from 1 = strongly disagree – 7 = strongly agree (“In general I do feel well informed about...”). Concerning the subjective knowledge of emerging technologies, participants indicated a moderate level of knowledge ($M = 3.50$, $SD = 1.94$) ($ICC_{\text{person}} = 0.48$, $ICC_{\text{tech}} = 0.12$).

Covariates

In addition, a number of covariates were assessed. Measurements of religiosity on a 10-point scale indicate a modest level, $M = 3.20$ ($SD = 2.23$). The political ideology of the sample (6-point scale, 1 = "very liberal" to 6 = "very conservative") showed a value of $M = 4.04$ ($SD = 1.55$). Moreover, the variable of deference to scientific authority has been identified as a salient factor in the influence of communicator effects on perceptions of credibility and trust (Brossard & Nisbet, 2007). Deference to scientific authority was measured using a 3-item scale adopted from C. Lee and Scheufele (2006) (e.g., "Scientists know best what is good for the public"). A 7-point scale was used, ranging from 1 = strongly disagree to 7 = strongly agree. Overall, the deference to scientific authority variable showed a high level of overall reliability ($\omega = .83$). There was a medium level of agreement with statements regarding whether scientists have the authority over scientific findings and decisions ($M = 4.98$, $SD = 1.23$).

Table 20. Overview on the operationalization of measures and statistics for study 3

Construct	Statistics					
	<i>M</i>	<i>SD</i>	<i>ICC</i> (<i>Person</i>)	<i>ICC</i> (<i>Tech</i>)	<i>Omega</i> (<i>within</i>)	<i>Omega</i> (<i>between</i>)
<i>Subjective knowledge of emerging technologies</i> (based on European Commission, 2013; Yang et al., 2017)						
(1) In general, I do feel well informed about this technology.	3.50	1.94	.48	.12		
<i>7-point-scale (1 = strongly disagree to 7 = strongly agree)</i>						
<i>Relevance perception</i> (based on Whitmarsh & O'Neill, 2010)						
(1) I will get personally involved to support biofuels.	3.84	1.83	.47	.13	.91	.98
(2) The issue of biofuels is personally relevant to me.						
(3) The issue of biofuels is personally important to me.						
<i>7-point-scale (1 = strongly disagree to 7 = strongly agree)</i>						
<i>Support emerging technologies</i> (based on Brossard & Nisbet, 2007; C. Lee & Scheufele, 2006)						
(1) There should be more federal funding for biofuels.	4.23	1.74	.45	.12	.86	.98
(2) Overall, I support the use of biofuels.						
<i>7-point-scale (1 = strongly disagree to 7 = strongly agree)</i>						
<i>Behavioral intentions emerging technologies</i> (based on C. Lee & Scheufele, 2006)						
(1) I will vote for a political party that supports Biofuels.	3.72	1.74	.55	.08	.87	.97
(2) I will get personally involved to support Biofuels.						
(3) I would like to receive more information on how to take further action to support Biofuels.						
(4) I will use products that are linked to Biofuels.						
<i>7-point-scale (1 = strongly disagree to 7 = strongly agree)</i>						

7. Study 3: Source Credibility Effects

Source credibility (based on Ohanian, 1990; Paul et al., 2022)

The scientist in the article is

(1) undependable/ dependable	4.92	1.18	.60	.05	.85	.99
(2) dishonest/honest						
(3) unreliable/reliable						
(4) untrustworthy/trust- worthy						
(5) inexpert/expert						
(6) inexperienced/ experienced						
(7) unknowledgeable/ knowledgeable						
(8) unqualified/qualified						

*7-point-scale semantic differ-
entials*

Scientist evaluation

The scientist in the article is

(1) unsympathetic/ sympathetic	4.82	1.23	.55	.05	.52	.97
(2) unfriendly/friendly"						

*7-point-scale semantic differ-
entials*

Message credibility (based on Gaziano & McGrath, 1986; Meyer, 1988)

This newspaper article is

(1) unfair/fair	4.70	1.20	.58	.04	.75	.96
(2) biased/unbiased						
(3) doesn't tell the whole story/tells the whole story						
(4) cannot be trusted/can be trusted						
(5) inaccurate/accurate						

*7-point-scale semantic differ-
entials*

Message evaluation

This newspaper article is

(1) unreadable/readable	4.93	1.41	.52	.09	.65	.92
(2) not interesting/interest- ing						

*7-point-scale semantic differ-
entials*

Religiosity (based on Anderson et al., 2014)

(1) How much guidance does religion pro- vide in your every- day life?	3.20	2.23

*10-point-scale (1 = "no guid-
ance at all" to 10 = "a great
deal of guidance")*

7. Study 3: Source Credibility Effects

<i>Political ideology</i> (based on Anderson et al., 2014)			
(1) Please indicate how socially liberal or conservative you are.	4.04	1.55	
<i>6-point-scale (1 = "very liberal" to 6 = "very conservative")</i>			
<i>Deference to scientific authority</i> (based on C. Lee & Scheufele, 2006)			
(1) Scientists know best what is good for the public.	4.98	1.23	.83
(2) It is important for scientists to get research done even if they upset people by doing it.			
(3) Scientists should do what they think is best, even if they have to persuade people that it is right.			
<i>7-point-scale (1 = strongly disagree to 7 = strongly agree)</i>			

7.2.4 Sample and Power Analysis

A preliminary power analysis was conducted for study 3 using G*Power (Faul et al., 2007), incorporating the eight experimental conditions as a between-subjects factor and the five technology conditions as a within-person factor. This analysis indicated that, for a medium effect size of $f = 0.25$ and a power level of .80, approximately six participants per group (for a total of 48 participants) would be required to detect the interaction between groups and conditions. For a comparable between-subjects design with 45 groups (representing the conditions), 50 participants per group would be necessary for a total sample size of 400 participants. Assuming a smaller effect size ($f = 0.1$), the between-subjects design would necessitate 306 participants per group, resulting in a total sample size of 2,448 participants. Conversely, the mixed design would require 29 participants per group, yielding a total sample size of 248 participants. Therefore, the objective was to attain a minimum sample size of at least 248 participants to detect a small effect size at a power level of 80% and an alpha level of 0.05.

The recruitment for study 3 was realized from February 27 to March 4, 2024, by Bilendi & Responi (2024). In total, 674 cases were collected, while 25 cases were excluded due to missing answers regarding the dependent variables and sociodemographic

information⁵⁹. This study's final sample consisted of 649 participants from the United Kingdom. As displayed in Table 21, the gender distribution was relatively balanced, with 47.1% male, 52.0% female, and 0.9% non-binary participants. The age of the sample ranged from 18 to 79 years ($M = 45.15$ years, $SD = 15.77$). With respect to educational background, a negligible proportion of the sample reported having no diploma (5.1%), while 50.5% possessed a high school diploma and 44.4% held a university degree.

Table 21. Sociodemographics of the sample for study 3

Sample details	Study source credibility effects $N = 649$	
	Frequency	Percentage
Gender		
Male	306	47.1%
Female	337	52.0%
Non-binary	6	0.9%
Age		
18-25	96	14.8%
26-35	117	18.0%
36-45	127	19.5%
46-55	103	15.9%
56-65	118	18.2%
>66	88	13.6%
Education		
No education diploma	33	5.1%
High School	328	50.5%
University Degree	263	40.5%
PhD	25	3.9%
Country of residence		
United Kingdom	649	100%

7.2.5 Data Analysis

For the study on *source effects*, linear mixed-effects models were conducted using the *lme4* package in R (Bates et al., 2015) for data analysis. The separate statistical models

⁵⁹ It was also checked whether respondents completed the questionnaire in under five minutes as a quality-control criterion.

are included in the [online appendix](#). All models were specified with a random intercept by technology and participant⁶⁰. Initially, as implied in Figure 35, two baseline models with random intercepts by participant and technology were conducted for the dependent variables of *message credibility* and *credibility of the scientist* to estimate variance components on the person and stimuli level (*RQ3.1*). Two models included the experimental manipulations of scientists' gender, age, and the presence of a picture as fixed effects terms. As shown in Figure 35, step 1, the two-way interactions of these factors were incorporated as fixed effects into the model.

In the analysis, *Average Marginal Effects (AMEs)* were used to estimate the main effects of individual variables (such as gender and age of the scientist) on the outcome variables (message credibility perception and scientist credibility perception), while averaging over the levels of other variables. This methodological approach facilitated a more nuanced comprehension of the impact of a specific variable, while concurrently accounting for the influence of other confounding factors. In the analysis, Average Marginal Effects (AMEs) were used to estimate the main effects of individual variables (such as scientist gender and age) on the outcome variables (message credibility and scientist credibility), averaging over the levels of other predictors. For gender (*RQ3.2*), AMEs were computed across the observed distribution of scientist age, providing an estimate of how gender alone affects the outcomes. Similarly, for age (*H3.1*), AMEs were calculated across the observed distribution of gender, yielding an estimate of the independent effect of age on message credibility and scientist credibility. In addition, the interaction of gender, age, and picture presence was tested (*H3.2*). Average Marginal Effects were computed separately within each picture condition to examine how the effects of scientist gender and age on credibility were moderated by the presence of a picture. AMEs were estimated with 95% confidence intervals. These analyses were conducted using the `avg_predictions` function in the R package “marginaleffects” (Arel-Bundock et al., 2024).

In order to detect the fit of mixed models with moderation terms concerning participants' prior attitudes (*H3.3*), as shown in Figure 35 (step 2), mixed models were conducted with the source variables of scientists' gender, scientists' age, and the presence of a picture and the two-way interactions of those variables, including the additional moderator variables as fixed effects. The correlations between the moderation variables

⁶⁰ Although maximal random-effects structures are generally recommended (Barr, 2013), random slopes were not included due to only five technology topics as stimuli and limited observations per participant, which would make slope estimation unstable.

specified in *H3.3* (support, behavioral intentions, subjective knowledge, and subjective relevance perception towards emerging technologies) were moderate to high ($r > .76$). To avoid multicollinearity issues, there was one separate model estimated for each of the moderator variable being entered as fixed effect. For instance, the moderator variable support towards emerging technologies was incorporated into the model without interaction, which was then compared to the respective model that incorporated interaction effects of the moderator variable (Figure 35, step 3).

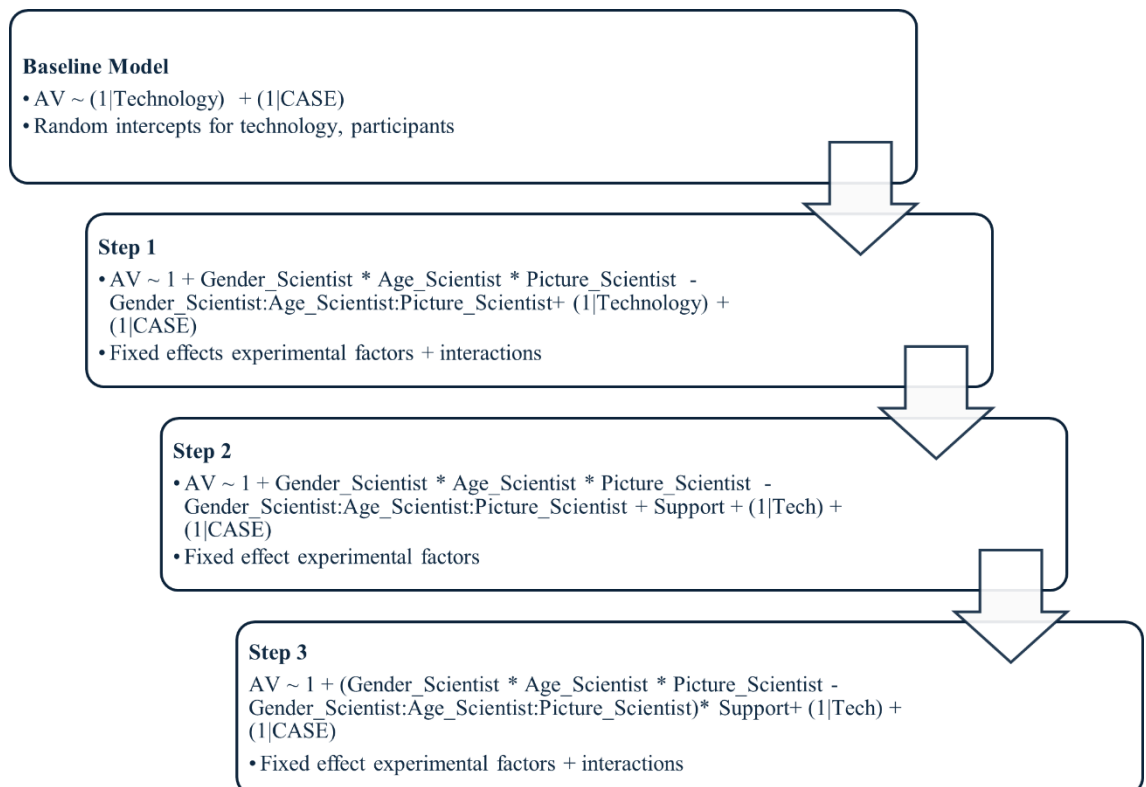
For technological *support*, the model predicting message credibility that did not incorporate an interaction term exhibited a superior fit to the data compared to the model that included such an interaction, $\chi^2(6) = 4.20, p = .64$ (Deviance = 7261.7, 7257.5; AIC = 7283.7, 7291.5). In the context of predicting scientists' credibility, a model with a fixed effect of support provided a superior fit to the data compared to a model incorporating an interaction term, $\chi^2(6) = 1.03, p = .98$ (Deviance = 6786.5, 6785.4; AIC = 6808.5, 6819.4). Additionally, for *behavioral intentions* concerning emerging technologies, the model predicting message credibility without an interaction term exhibited a superior fit for the data compared to a model incorporating an interaction term ($\chi^2(6) = 8.29, p = .21$; Deviance = 7257.8, 7249.5; AIC = 7279.8, 7283.5). In the context of predicting scientists' credibility, a model that was specified without a fixed effect of the interaction term with behavioral intentions provided a better fit to the data compared to a model with an interaction term ($\chi^2(6) = 3.86, p = .69$; Deviance = 6780.5, 6776.6; AIC = 6802.5, 6810.6).

For *subjective knowledge*, including the interaction in the random-intercept model predicting message credibility perception did not significantly improve model fit compared to the simpler model without the interaction ($\chi^2(6) = 10.19, p = .11$; Deviance = 7300.4, 7290.3; AIC = 7322.4, 7324.3), indicating that the simpler model provided an adequate fit to the data. Similarly, in predicting scientists' credibility, a model without the interaction of subjective knowledge exhibited a more optimal fit to the data in contrast to a model incorporating an interaction term ($\chi^2(6) = 10.29, p = .11$; Deviance = 6834.8, 6824.5; AIC = 6856.8, 6858.5). In the context of *subjective relevance perception* predicting message credibility, including the interaction in the random-intercept model predicting message credibility from subjective relevance perception did not significantly improve model fit compared to the simpler model without the interaction ($\chi^2(6) = 8.16, p = .22$; Deviance = 7305.5, 7297.3; AIC = 7327.5, 7331.3). Conversely, for the prediction of scientists' credibility, a model lacking the interaction with the relevance perception

exhibited a superior fit to the data compared to a model incorporating an interaction term, $\chi^2(6) = 3.40, p = .75$ (Deviance = 6819.6, 6816.2; AIC = 6841.6, 6850.2).

Concerning the potential influence of the moderator variable of *participants gender* on message credibility and scientists' credibility (RQ3.3), the interaction models did not improve model fit. This was evident for message credibility perception, where a likelihood-ratio test showed that adding the interaction between participant gender and scientist gender did not improve model fit compared to the random-intercept model without the interaction, $\chi^2(2) = 0.02, p = .99$ (Deviance = 7320.3 vs. 7320.2; AIC = 7344.3 vs. 7348.2). Moreover, the model predicting scientists' credibility showed that the simpler model provided better fit to the data $\chi^2(2) = 0.32, p = .85$ (Deviance = 6847.4, AIC = 6871.4) compared to the interaction model (Deviance = 6847.1, AIC = 6875.1). In summary, the results from the mixed models without interaction terms including the moderation variables were reported for all analyses.

Figure 35. Data analysis plan study 3 for the mixed effects data structure with stepwise inclusion of fixed effects



7.3. Results

This section gives an overview of the results of the third study on source effects on credibility perceptions toward the message and the source of information in newspaper articles in the context of emerging technologies. Initially, the impact of person-level and topic-level differences on credibility assessments will be examined (7.3.1). Subsequently, the impact of source-related cues, including scientists' gender, age, and the presence of a picture, will be investigated (7.3.2). Finally, the moderating influence of respondents' gender and prior attitudes on credibility perceptions will be evaluated (7.3.3).

7.3.1 The Influence of Person-Level and Topic-Level Differences

In relation to *RQ3.1*, two baseline models with random effects for participants and technology stimuli were specified to predict the variance components of the two outcomes of credibility perceptions. For the model predicting *message credibility*, the proportion of variance explained by the random effects of persons and technology stimuli was 70%, indicating that the mixed effects model structure was justified. The total variance attributed to the explanation of message credibility was 1.73, with the variability between participants contributing to 58% of the total variance, while variability between technology newspaper articles accounted for 4% of the variance, leaving 38% unexplained variance. A parallel analysis was conducted for the model predicting *scientists' credibility*, resulting in 65 % variance explained by random effects, thereby substantiating the mixed effects model structure. The total variance of 1.69 for scientists' credibility was explained by differences between participants to the extent of 60 %, and by differences between technology stimuli to the extent of 5 %, leaving 35 % unexplained variance.

In response to *RQ3.1*, the ICC values indicate that a considerable proportion of the observed variance in message credibility and scientist credibility was attributable to individual differences among participants. A smaller portion of this variance was due to differences in technology stimuli. These findings suggest a moderate level of agreement in credibility perceptions at the participant level, with minor variability associated with technology stimuli.

7.3.2 Source Cues of Gender, Age, and Picture of the Scientist

Results revealed that participants indicated relatively high credibility perceptions for different newspaper conditions on technology issues. As shown in Table 22, the mean ratings

for the technology newspaper conditions were comparable, with the highest value reported for *message credibility* in the personalized medicine condition ($M = 4.83$; $SD = 1.23$), and the lowest rating for the functionally graded materials condition ($M = 4.64$; $SD = 1.15$). In terms of message credibility, the highest-rated condition was when the scientist was male, older and showed a picture of the scientist, which received an average score of 4.76 ($SD = 1.26$). The lowest-rated condition was for a scientist which was male, younger and accompanying a picture, with an average score of $M = 4.63$ ($SD = 1.15$). The *credibility of the scientist* was rated as considerable high, especially for the condition of personalized medicine ($M = 5.07$; $SD = 1.20$), while it was the lowest for functionally graded materials ($M = 4.87$; $SD = 1.14$), and electric vehicles ($M = 4.87$; $SD = 1.29$). In the context of scientists' credibility, the presentation of the scientist as male, older, and accompanied by a picture once again garnered the highest rating ($M = 5.05$, $SD = 1.23$). In contrast, the lowest rating was observed for the condition involving a male scientist who was younger and also showed a picture of the scientist ($M = 4.85$, $SD = 1.13$). These descriptive findings suggest that older male scientists with a picture were perceived as the most credible in both message and scientists' credibility, while younger male scientists with a picture were perceived as the least credible in both categories.

Table 22. Means and standard deviations of dependent variables for experimental conditions

Condition	<i>n</i>	Message Credibility	Scientists' Credibility
Newspaper articles			
issues			
Biofuels	649	4.68 (1.16)	4.89 (1.15)
Electric vehicles	649	4.66 (1.31)	4.87 (1.29)
Functionally graded materials	649	4.64 (1.15)	4.87 (1.14)
Personalized medicine	649	4.83 (1.23)	5.07 (1.20)
Precision agriculture	649	4.69 (1.17)	4.91 (1.14)
Scientist condition			
Male/young	359	4.71 (1.17)	4.87 (1.16)

Male/young/picture	360	4.63 (1.15)	4.85 (1.13)
Male/old	360	4.68 (1.16)	4.87 (1.15)
Male/old/picture	362	4.76 (1.26)	5.05 (1.23)
Female/young	356	4.68 (1.37)	4.91 (1.36)
Female/young/picture	367	4.73 (1.29)	4.93 (1.25)
Female/old	361	4.70 (1.17)	4.92 (1.13)
Female/old/picture	362	4.72 (1.13)	5.00 (1.13)
Neutral gender/no age	358	4.69 (1.12)	4.90 (1.10)

$N = 649$ respondents, $n = 3,245$ observations. Means and standard deviations for the average responses of participants for the technology newspaper conditions and the combination of gender, age and presence of a picture in scientists concerning the dependent variables of message credibility and scientists' credibility.

Table 23 presents the bivariate correlations between the five *technology conditions* and *message credibility*. The findings reveal that all correlations are positive and statistically significant, suggesting a positive relationship between the credibility of one technology condition and the credibility of the other conditions. A noteworthy correlation exists between biofuels and other technologies, with moderate to strong relationships observed with electric vehicles ($r = .70, p < .001$) and functionally graded materials ($r = .75, p < .001$). A slightly lower yet still moderate correlation was detected for personalized medicine and electric vehicles ($r = .65, p < .001$). The aforementioned findings collectively indicate that the message credibility perceptions of these technologies are moderately aligned, with the strongest correlations observed between biofuels and functionally graded materials.

As shown in Table 24, the highest correlations between *scientists' credibility* and technology issues were identified between biofuels and functionally graded materials, as well as between biofuels and precision agriculture, both exhibiting an $r = .79$ ($p < .001$) coefficient. A comparable correlation was observed between functionally graded materials and precision agriculture ($r = .78, p < .001$). The lowest correlation was found between electric vehicles and personalized medicine ($r = .69, p < .001$), suggesting a slightly weaker but still significant relationship compared to the other technology pairs. These results highlight the generally strong alignment in the perception on the credibility perception of scientists, with the highest correlations between biofuels, functionally graded materials, and precision agriculture.

Table 23. Bivariate correlations between technology conditions and message credibility

Technology condition	Biofuels	Electric vehicles	Functionally graded materials	Personalized medicine	Precision agriculture
Biofuels	1.00	.70***	.75***	.72***	.74***
Electric Vehicles	.70***	1.00	.70***	.65***	.69***
Functionally graded materials	.75***	.70***	1.00	.73***	.74***
Personalized medicine	.72***	.65***	.73***	1.00	.69***
Precision agriculture	.74***	.69***	.74***	.69***	1.00

Pearson's *r* correlations, *** $p < .001$, $n = 649$

Table 24. Bivariate correlations between technology conditions and scientists' credibility

Technology condition	Biofuels	Electric vehicles	Functionally graded materials	Personalized medicine	Precision agriculture
Biofuels	1.00	.75***	.79***	.75***	.79***
Electric Vehicles	.75***	1.00	.73***	.69***	.74***
Functionally graded materials	.79***	.73***	1.00	.75***	.78***
Personalized medicine	.75***	.69***	.75***	1.00	.74***
Precision agriculture	.79***	.74***	.78***	.74***	1.00

Pearson's *r* correlations, *** $p < .001$, $n = 649$

The objective of this study was to identify the impact of the scientist's gender on the perceived credibility of the message and the scientist's perceived credibility (*RQ3.2*). It was hypothesized that the credibility of the message and the scientists would be higher

in older scientists compared to younger ones (*H3.1*). Furthermore, the conditional effect of the presentation of the scientist conveying a picture of the scientist will be further evaluated according to *H3.2*.

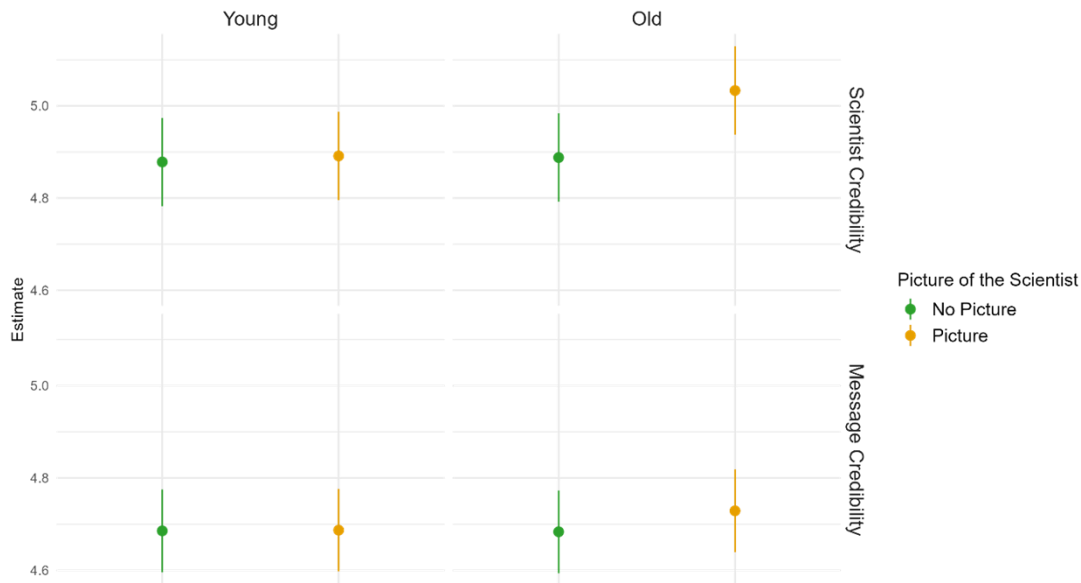
As outlined in more detail in chapter 7.2.5, the first linear mixed model with message credibility as outcome variable predicted the source effect of the three independent variables gender, age, and picture of the scientist which were specified as fixed effects in the model representing the factor levels of the conditions, as well as the two-way interactions of those variables. According to Table 25, Model 1, in comparison to the null model that predicted message credibility, the mixed model incorporating the fixed effects of gender, age, and the presence of a picture exhibited a negligible increase (0.03%) in the overall explained variance (conditional $R^2 = 0.71$) of message credibility. For the model predicting scientists' credibility (see Table 25, Model 2) including the source variables resulted in overall explained variance of 76% of which the fixed effects explained a minimum of 0.3% of the variance of the communicators credibility. Regarding the main effect of *scientists' gender* on credibility perceptions (*RQ3.2*), Table 25, Model 1 shows that there were no differences between female and male scientists shown in the newspaper articles in terms of predicting *message credibility* ($b = 0.00$, 95% CI [-0.09, 0.09], $p = .99$). Conversely, for the outcome of *scientists' credibility*, no influence of gender of the scientist could be detected ($b = 0.04$, 95% CI [-0.04, 0.13], $p = .27$) (see Table 25, Model 2).

Regarding the impact of scientists' age (*H3.1*), no significant differences were observed between younger and older scientists in relation to their ability to predict message credibility ($b = 0.00$, 95% CI [-0.09, 0.10], $p = .88$). Furthermore, the interaction between scientists' gender and scientists' age did not demonstrate a significant effect on message credibility ($b = -0.01$, 95% CI [-0.09, 0.07], $p = .84$) (see Table 25, Model 1). Similarly, no significant differences were observed in the credibility of the scientist as a communicator across different age groups ($b = 0.01$, 95% CI [-0.07, 0.09], $p = .72$). This finding remained consistent when considering the interaction between scientists' gender and age ($b = -0.00$, 95% CI [-0.10, 0.08], $p = .84$) (see Table 25, Model 2).

Furthermore, as implied in Table 25, Model 1, the *presence of a picture* (*H3.2*) did not affect the evaluation of *message credibility* ($b = -0.00$, 95% CI [-0.09, 0.08], $p = .92$). Additionally, the interaction between the gender of the scientists and the presence of a picture ($b = 0.01$, 95% CI [-0.09, 0.11], $p = .82$) and the age of the scientist and the presence of a picture ($b = 0.04$, 95% CI [-0.06, 0.15], $p = .40$) were not significant in

predicting message credibility. To further elaborate on these findings, *average marginal effects (AMEs)* were computed to illustrate the impact of scientists' age on message credibility in the presence or absence of a picture. As Figure 36 shows, the *AMEs* for younger scientists indicated no difference in message credibility whether a picture was displayed ($AME = 4.69$, 95% CI [4.59, 4.77], $p < .001$) or not displayed ($AME = 4.69$, 95% CI [4.59, 4.77], $p < .001$). However, for older scientists, the inclusion of a picture marginally increased message credibility ($AME = 4.72$, 95% CI [4.63, 4.81], $p < .001$) compared to when no picture was shown ($AME = 4.68$, 95% CI [4.59, 4.77], $p < .001$), indicating a slight improvement in perceived message credibility.

On the *credibility perception of the scientist*, no statistically significant interaction effect was found between the scientist's gender and the presence of a picture on the communicator's credibility ($b = -0.05$, 95% CI [-0.14, 0.05], $p = .34$). However, a significant interaction was observed between the scientist's age and the presence of a picture ($b = 0.13$, 95% CI [0.04, 0.22], $p = .005$), suggesting that scientists of advanced age who were depicted with a picture were perceived as more credible. Concerning the credibility of scientists, the average marginal predictions illustrated in Figure 36 indicated a minimal difference for younger scientists, where conditions with a picture ($AME = 4.89$, 95% CI [4.79, 4.98], $p < .001$) were nearly identical to conditions without a picture ($AME = 4.87$, 95% CI [4.78, 4.97], $p < .001$). In contrast, older scientists demonstrated a more substantial increase in credibility when a picture was present ($AME = 5.03$, 95% CI [4.93, 5.12], $p < .001$) compared to when no picture was displayed ($AME = 4.88$, 95% CI [4.79, 4.98], $p < .001$). This finding indicates a significant enhancement in perceived credibility for older scientists when visual representation is present.

Figure 36. Average marginal effects (AMEs) for conditions of scientists age and presence of a picture

$n = 649$. Average marginal effects (AMEs) for the age of the scientist and the presence of a picture of the scientist concerning credibility of the message and credibility of the scientist with 95 % CI (scale: 7-point-scale semantic differentials).

Furthermore, according to *RQ3.3*, the moderating influence of *respondents' gender* on the effect of gender of the source on message and source credibility was investigated. Given that the mixed models with main effects of respondents' gender as predictor were considered a better fit to the data than the respective models with interaction effects of respondents' gender and the gender of the source (see chapter 7.2.5), results will be interpreted only concerning main effects of respondents' gender. The mixed model yielded a 71% explanation of *message credibility* variance attributable to fixed and random effects, with only 0.41% explained by fixed effects alone. As shown in Table 25, Model 1, in comparison to the reference category of male gender, neither the female gender of participants ($b = -0.15$, 95% CI [-0.02, 0.31], $p = .084$), nor non-binary gender of participants ($b = 0.12$, 95% CI [-0.74, 0.99], $p = .77$), predicted message credibility. The results of the analysis indicated that 76% of the variance in *scientist credibility* could be attributed to fixed and random effects, with a mere 0.63% being explained by fixed effects alone. In this model, female ($b = -0.14$, 95% CI [-0.30, 0.03], $p = .10$) or non-binary gender of participants ($b = 0.00$, 95% CI [-0.87, 0.87], $p = .99$) showed no effect on the credibility perception concerning the scientist (see Table 25, Model 2). Thus, in

answering *RQ3.3*, there was no substantial interaction effect of participants' gender concerning the gender of the source on message and source credibility.

Table 25. Results of the linear mixed-effect models predicting message credibility and credibility of the scientist in newspaper articles on technology issues

	Model 1		Model 2	
	<i>b</i>	95% <i>CI</i>	<i>b</i>	95% <i>CI</i>
Fixed effects				
Gender scientist (female)	0.00	-0.09 – 0.09	0.04	-0.04 – 0.13
Age scientist (old)	0.01	-0.08 – 0.10	0.01	-0.07 – 0.09
Picture scientist (picture)	-0.00	-0.09 – 0.08	0.04	-0.04 – 0.12
Gender scientist female x age scientist old	-0.02	-0.12 – 0.09	-0.00	-0.10 – 0.08
Gender scientist female x picture scientist	0.01	-0.09 – 0.11	-0.05	-0.14 – 0.03
Age scientist old x picture scientist	0.04	-0.06 – 0.15	0.13**	0.04 – 0.22
Gender participant (female)	-0.15	-0.31 – 0.02	-0.14	-0.30 – 0.03
Gender participant (non-binary)	0.12	-0.74 – 0.99	0.00	-0.87 – 0.87
Support	0.09***	0.07 – 0.11	0.08***	0.06 – 0.10
Behavioral intentions	0.10***	0.08 – 0.13	0.10***	0.07 – 0.12
Subjective knowledge	0.05***	0.03 – 0.07	0.04***	0.02 – 0.06
Subjective relevance perception	0.05***	0.03 – 0.07	0.06***	0.04 – 0.08

N = 649, *n* = 3,245 observations. Fixed effects are displayed for the model with experimental conditions of gender of the scientist, age of the scientist, and presence of a picture, as well as interactions. Additional effects for the moderator variables (gender participant, issue support, behavioral intentions, subjective knowledge, subjective personal relevance perception) were entered step-wise in respective models. Non-standardized regression coefficients are reported. Reference groups for the categorical variables: gender of the scientist = male; age of the scientist = young, picture of the scientist = no picture; gender of the participant = male.

p* < 0.05; *p* < 0.01; ****p* < 0.001

7.3.3 Moderating Influence of Prior Attitudes

To detect the relationship between the moderator variables specified in *H3.3*, correlations were conducted. As Table 26 shows, the correlations between prior attitudes towards emerging technologies were moderate to high ($r > .76$). Specifically, the correlations between support and behavioral intentions ($r = .88, p < .001$), as well as between subjective relevance perception and behavioral intentions ($r = .91, p < .001$), were particularly strong. However, this high degree of correlation could potentially indicate multicollinearity, which might pose issues when including all of these moderators in a single statistical model, leading to inflated standard errors and less reliable estimates (J. Cohen et al., 2003). Therefore, analysis with separate mixed models were conducted for the respective moderator variables.

Table 26. Bivariate correlations between moderator variables

Moderator variables	Support	Behavioral intentions	Subjective knowledge	Subjective relevance perception
Support	1.00	.88***	.76***	.86***
Behavioral intentions	.88***	1.00	.85***	.91***
Subjective knowledge	.76***	.85***	1.00	.87***
Subjective relevance perception	.88***	.91***	.87***	1.00

Pearson's r correlations, *** $p < .001$, $n = 649$

According to *H3.3*, the *prior attitude* towards emerging technologies was expected to interact with the source variables of gender, age, and picture in order to increase credibility perceptions of the message and the source. The model fit estimation (see chapter 7.2.5) revealed that the mixed models with fixed effects of the predictors of support, behavioral intentions, subjective knowledge, and subjective relevance perception yielded a superior fit to the data compared to models incorporating interaction terms. Consequently, these models were employed for hypothesis testing. In the model employing *support of emerging technologies* as the predictor, a total of 69% of the variance in message

credibility was explained by both fixed and random effects. Furthermore, the fixed effects accounted for an additional 2% of the variance in message credibility. As Table 25, Model 1 shows, the significant main effect indicates that recipients' support towards emerging technologies positively predicted credibility perceptions of the message ($b = 0.09$, 95% CI [0.07, 0.11], $p < .001$). The model with scientists' credibility as outcome showed an overall variance explanation of 74%, while the attributes of the source cue variables, as well as support as fixed effects, explained 2% of the variance. As shown in Table 25, Model 2, support of emerging technologies significantly predicted source credibility ($b = 0.08$, 95% CI [0.06, 0.10], $p < .001$).

Subsequently, in a series of models, the influence of *behavioral intentions towards emerging technologies* was incorporated as a fixed effect. The overall explained variance for message credibility was 69%, with a marginal R^2 of 0.02. The findings indicate a positive association between behavioral intentions toward emerging technologies and message credibility ($b = 0.10$, 95% CI [0.08, 0.13], $p < .001$) (see Table 25, Model 1). With respect to the credibility of scientists, 74% of the overall variance was explained, and the inclusion of fixed effects into the model accounted for 3% of the variance in credibility. Furthermore, behavioral intentions regarding emerging technologies were found to be positively associated with the perceived credibility of scientists ($b = 0.10$, 95% CI [0.07, 0.12], $p < .001$) (see Table 25, Model 2).

In the following mixed model, *subjective knowledge* of emerging technologies was incorporated as a predictor. This model demonstrated that 70% of the variance in message credibility was explained, considering both fixed and random effects. The fixed effects alone explained less than 1% of the variance in message credibility (marginal $R^2 = 0.007$). As shown in Table 25 (Model 1), subjective knowledge of emerging technologies exhibited a positive association with an enhancement in message credibility ($b = 0.05$, 95% CI [0.03, 0.07], $p < .001$). Regarding scientists' credibility, the mixed model demonstrated its capability to explain 75% of the variance, with the fixed effects contributing only a negligible amount of variance (marginal $R^2 = 0.007$). In this case, the subjective knowledge of emerging technologies positively predicted the credibility perception of the scientist ($b = 0.04$, 95% CI [0.02, 0.06], $p < .001$) (see Table 25, Model 2).

The final outcome related to prior attitudes regarding the issue investigated the influence of the *subjective relevance perception of emerging technologies*. Overall, the mixed model demonstrated a 70% explanation of the variance in message credibility, with the majority of the variance being attributed to random effects (marginal $R^2 = 0.006$).

Subjective relevance perception toward emerging technologies was linked to a positive effect on message credibility ($b = 0.05$, 95% CI [0.03, 0.07], $p < .001$) (see Table 25, Model 1). About the credibility perception of scientists, 75% of the variability was attributed to fixed and random effects in the model, incorporating subjective relevance perception as an additional fixed effect, while a mere 1% of the variance was explained by fixed effects. Furthermore, when the topic was perceived as more personally relevant, scientists' credibility was rated higher ($b = 0.06$, 95% CI [0.04, 0.08], $p < .001$) (see Table 25, Model 2).

In addressing *H3.3*, it was observed that support, behavioral intentions, subjective knowledge, and subjective relevance perception directly enhanced credibility perceptions for both the message and the scientist. This finding suggests that prior attitudes exert a straightforward, positive influence on credibility perceptions rather than interacting with specific source attributes.

7.4 Summary and Study Specific Discussion

The present study investigated the influence of the source variables of the sources' gender, age, and the visual presentation of scientists as communicators in the context of science communication, particularly regarding emerging technologies. Furthermore, the study identified significant influences prior attitudes to the technology issues on credibility perceptions.

Person-level and technology-level differences

Referring to *RQ3.1*, the analysis concerning study 3 highlighted that individual differences significantly influence credibility perceptions. Accordingly, the mixed model explaining message credibility demonstrated a substantial variance explained by participant differences, similarly, reflected in the model predicting scientist credibility perceptions. In accordance with the findings of study 1, as well as study 2, this study also indicates that individual differences at the personal level are more relevant than topic-level differences in shaping credibility perceptions of the message and the source. It was also evident that the influence of technology-related topics was negligible, contributing only a small amount of variance to the credibility perception of the message and the source.

Source cues of gender, age, and picture of the scientist

When considered as a whole, the source cues examined, including gender, age, and the presence of a scientist, provided nuanced insights into credibility perceptions in technology-related newspaper articles. Participants exhibited relatively high credibility ratings across various newspaper conditions, with the technology condition of personalized medicine consistently receiving higher scores for both message and scientist credibility.

As indicated by the existing literature, the influence of communicator gender on perceptions of credibility *RQ3.2* is complex and multifaceted (Flanagin & Metzger, 2007; Pornpitakpan, 2004). To support findings of prior research concerning experts in news media (Greve-Poulsen et al., 2021; Paul et al., 2022), the results of this study revealed no substantial disparities in credibility perceptions of the message and the source based on the gender of the scientist serving as the source of communication. However, there are also contrasting results showing that female sources are perceived as more credible (Biggam et al., 2019) or likable (Hubner & Bullock, 2024) compared to male sources. Nevertheless, the absence of findings in this study suggests that the scientist's perceived expertise may have a significant impact on gender not serving as a cue (Paul et al., 2022). While the activation of gender stereotypes has been shown to influence credibility perceptions, particularly in lower-involvement scenarios (Dasgupta & Asgari, 2004), the lack of significant differences in this study suggests that audiences are increasingly challenging these biases. As to be evaluated in future studies, in-depth engagement with content can potentially encourage readers to adopt a more rational approach in evaluating the message and the scientist's qualifications (Deaux & Lewis, 1984).

In sum, these varying outcomes contribute to the ongoing discourse about the role of gender as a source cue in credibility assessments, offering several implications for understanding how gender stereotypes operate within the context of scientific communication (Cave et al., 2023; Loverock & Hart, 2018). For instance, these discrepancies may stem from variations in study design, participant demographics, or specific contexts in which gender is assessed (Pearson, 1982). Thus, further research is necessary to understand how situational factors and audience characteristics contribute to credibility evaluations.

The findings regarding *RQ3.3* indicate that respondents' gender did not significantly influence message credibility or the credibility of the message or the scientist. To this end, the context of the study may have been a factor in the observed results. Contrary to the findings of other studies that documented the gender affinity effect — wherein

individuals exhibited a preference for communicators of the same gender (Dolan, 2008) — or the opposite effect, that scientists were evaluated more favorably as a source of the same gender (Hubner & Bullock, 2024), the current study's findings suggest that participants evaluated scientists more holistically. Such a perspective finds support in research indicating that individuals may bypass gender stereotypes when engaging deeply with content, favoring rational evaluations of the message (Deaux & Lewis, 1984). Research indicated that additional demographic factors, including age and education level can moderate perceptions of credibility. As proposed in persuasion research, the influence of participant gender might also interact with prior attitude and knowledge levels (Cacioppo & Petty, 1980; Eagly & Carli, 1981), which might be an additional perspective for future investigations.

In a similar vein to the absent main effect of the sources' gender, the age of the source did not appear to influence message credibility (*H3.1*), as evaluations received by younger and older scientists were comparable. In the context of science communication, expertise is frequently associated with professional status, with age serving as a peripheral cue, as theorized by persuasion theory (Puckett et al., 1983). It can be posited that older experts are often regarded as the most credible due to the interplay of age, perceived expertise, and traditional role perceptions that favor male authority figures (Weibel et al., 2008). The null effect observed in this study may be attributable to the fact that the age of a source is frequently not a distinguishing factor in media portrayals (Edström, 2018). However, a substantial interaction was identified between scientists' age and the presence of a picture, suggesting that scientists depicted with a picture were perceived as more credible than those displayed without a picture. This finding supported *H3.2*, suggesting that the visual representation has the potential to enhance credibility perceptions for older scientists.

Furthermore, the average marginal effects analysis further illustrated that while younger scientists maintained stable credibility ratings regardless of picture presence, older scientists experienced a notable increase in credibility when a picture was included. Therefore, the concept of visual congruency is vital to comprehending these findings. To illustrate, a senior scientist engaged in discourse on established scientific principles stands to benefit from visual representation that underscores his expertise, thereby creating a congruency that resonates with audience expectations. Accordingly, the visual representations may have functioned as peripheral cues that influenced attitudes and beliefs without necessitating detailed cognitive processing, particularly when individuals lack the

motivation or expertise to critically evaluate the content (Chaiken, 1980; Peng et al., 2023). Consequently, depictions of scientists, particularly those of advanced age, have been observed to elicit stereotypes associating age with expertise and discernment, resulting in positive appraisals (Finkelstein et al., 2000; Hummert et al., 1998). It would be worthwhile to explore whether the use of images showing scientists in professional settings, such as laboratories, can further augment the persuasive efficacy of their communication. These images might have the potential to enhance credibility by aligning with audience expectations of scientific work (Gheorghiu et al., 2017; González et al., 2017).

Influence of prior attitudes on credibility perceptions

Further analysis related to *H3.3* examined how individuals' prior attitudes toward emerging technologies influence their perceptions of credibility. When individuals possess established views on a topic, their favorable predispositions — measured through support, behavioral intentions, subjective knowledge, and subjective personal relevance perception — consistently predict higher credibility ratings for the scientific message and its source. This is in line with the results of Yuan et al. (2019) who found that preexisting positive attitudes toward genetically modified organisms (GMOs) were significantly associated with higher assessments of message quality and greater likeability of the message source. Surprisingly, however, the present study found no significant moderating effects of source cues (e.g., age or gender) and prior predispositions on credibility perceptions themselves. In other words, while prior attitudes clearly shaped credibility perceptions, these predispositions did not systematically interact with the manipulated source characteristics to influence broader attitudinal outcomes. This suggests that, although people with favorable prior beliefs tend to view scientific sources as more credible, the impact of specific visual source cues on attitude change remains relatively consistent across different levels of predisposition.

As Chaiken and Maheswaran (1994) have argued, source credibility has its greatest persuasive impact when audience members lack strong preexisting attitudes. However, when such attitudes are well-formed, they become the dominant heuristic in shaping credibility judgments, which diminishes the influence of peripheral source characteristics (Chaiken, 1980; Petty & Cacioppo, 1986a). These findings are also consistent with the Elaboration Likelihood Model, which states that individuals are more likely to engage in central route processing under conditions of high personal relevance and familiarity (Petty & Cacioppo, 1986a, 1986b).

Implications and limitations

This study has several limitations that affect the generalizability and depth of its findings, particularly regarding the influence of prior attitudes on perceptions of credibility. First, the limited range of source characteristics, such as gender, age, and pictures of the source, may have constrained the potential for interaction effects with prior attitudes. Previous research has shown that audience responses to credibility cues are often heightened when source characteristics sharply confirm or diverge from audience expectations (Kunda, 1990; Roh et al., 2015). Likewise, variations in technological expertise have been shown to illuminate how non-scientific actors, such as lobbyists or YouTubers, can lower perceived credibility (Andrews et al., 2025; L. König & Jucks, 2019). Audiences may also adjust their perceptions of the source's credibility in nuanced ways based on subtle variations in the communicator's cultural background or appearance (Eaton et al., 2020; Eom et al., 2025). Furthermore, this study did not consider the influence of message content variations, such as tone or framing. Prior research indicates that the style and complexity of content can substantially affect how audiences perceive both the message and the communicator's credibility. Scientific sources might transport the evaluation of factuality, especially when the issue is perceived as highly personally relevant (Frewer et al., 1997, 1999).

Future studies could also test the long-term effects of the sleeper effect, which proposes that changes, such as shifts in perceived credibility, can strengthen over time rather than occurring immediately after exposure to a message (Kumkale & Albarracín, 2004; Pratkanis et al., 1988). Along these lines, research could further investigate cognitive mechanisms explaining why messages followed by discounting cues may retain or even gain persuasive influence. Examples include memory decay of the cue and primacy of message content (Kumkale & Albarracín, 2004; Pratkanis et al., 1988). Additionally, the sleeper effect is expected to be more prevalent among individuals with a high need for cognition, suggesting that respondent's motivation and the ability to process information play key roles in delayed credibility reassessment (Priester et al., 1999).

Addressing these limitations would expand understanding of how attitudes influence credibility judgments and clarify when source attributes become more or less relevant in shaping trust and credibility in scientific communication. This approach is congruent with the overarching objective of enhancing science communication strategies to cultivate public trust, particularly in the domain of emerging technologies, which are

characterized by elevated degrees of uncertainty and heterogeneous public attitudes (Barnett et al., 2007; Gustafson & Rice, 2019).

Conclusion

Overall, this research confirmed that source credibility perception is a multifaceted construct. While for example Miller, J., D. and McReynolds (1973) emphasized that male communicators have historically been regarded as more competent, recent investigations of gendered perceptions of experts suggest that a communicator's gender is not necessarily a determining factor in audience perceptions of credibility (Paul et al., 2022; Yeo et al., 2022). According to the findings of the present study, visual representations of scientists serve as immediate cues that influence audience judgments on the credibility of the communicator. For instance, a well-composed photograph of an older scientist exhibiting confidence and professionalism may reinforce the idea that they possess significant authority in their field. Conversely, if the visual representation does not align with audience expectations or portrays the scientist unfavorably, it may detract from their perceived credibility. This interplay between age and visual representation is of particular importance in the context of science journalism. It is incumbent upon journalists to exercise discernment in the manner in which they depict scientists in their articles, taking into account not solely the content of the message but also the way the combination of text and visual cues can influence audience perceptions.

These findings underscore the notion that favorable preexisting attitudes serve as a powerful lens through which individuals evaluate the trustworthiness of scientific information. Positive attitudes toward a given topic have been shown to influence the perception of credibility in related messages, often superseding the impact of specific source attributes. However, future research should aim to include more diverse demographic groups and utilize longitudinal designs to assess how attitudes evolve over time and influence credibility perceptions. Finally, the interaction between source characteristics and prior attitudes could be further explored, particularly in different contexts, to gain deeper insights into the dynamics of credibility in science communication. Addressing these limitations will enhance the robustness of findings and contribute to a more comprehensive understanding of how attitudes shape perceptions of credibility in scientific discourse.

8. Discussion and Conclusion

This dissertation aimed to investigate the influence of contextual factors and individual variables on attitude formation regarding emerging technologies, with a specific focus on the cognitive processes involved. In the following chapter, the main research objectives and results of the three empirical studies (8.1) are summarized. Additionally, the theoretical and methodological limitations of the empirical studies are discussed (8.2). Furthermore, implications for science communication research are presented (8.3), followed by concluding remarks (8.4).

8.1 Summary

Media reporting plays a crucial role in shaping public attitudes toward emerging technologies because people generally have limited direct knowledge and rely on mediated information (D. A. Scheufele & Lewenstein, 2005; Takahashi & Tandoc, 2016). The *media framing* of technologies such as AI or biotechnology in news coverage can promote understanding and acceptance, or conversely, trigger fear, skepticism, and polarization (Anderson et al., 2014; Huijts et al., 2012; D. A. Scheufele & Krause, 2019). Despite the theoretical recognition of media effects (see for example Nisbet et al., 2002), there is a notable research gap in the *experimental investigation* of how media reporting shapes attitudes towards emerging technologies, particularly with respect to the cognitive processes underlying attitude formation. This dissertation examined the underexplored *cognitive perspective* as a key mechanism through which audiences process media messages about emerging technologies. Attitude formation is therefore conceptualized as the essential cognitive process by which individuals evaluate an attitude object with varying levels of thinking effort (elaboration), which is shaped by their motivation and ability (Petty & Cacioppo, 1986a, 1986b).

Cognitive elaboration is significant in this regard because it anticipates the impact of message and source elements on attitude intensity, availability, and resistance to change (Petty et al., 1995). This focus on information processing is highly relevant in science communication because audiences interpret media messages about scientific topics using either detailed reasoning or simple heuristics shaped by prior beliefs and framing (Fiske & Taylor, 2017; C. Lee et al., 2005). The scientific literacy view posits that greater public knowledge leads to increased support for scientific developments. However, this view has only limited empirical support (Allum et al., 2008; Miller, J. D., 2004). Conversely, the "cognitive miser" perspective suggests that people often rely on heuristic

cues, such as media messages or preexisting values, rather than processing detailed information, to form their attitudes (Ho et al., 2008; Taylor, 1981). Empirical evidence from science communication research provides more consistent support for the latter view, highlighting the role of audience characteristics, such as prior knowledge, prior attitudes, and value predispositions, in attitude formation (Ho et al., 2010; Holden & Karsh, 2010; C. Lee et al., 2005; Nisbet, 2005). Persuasion theories reconcile these perspectives by explaining how individuals process information differently based on their motivation and ability, depending on their level of engagement with the content, with alternating heuristic and systematic processing modes (Chaiken, 1980; Petty & Cacioppo, 1986a, 1986a).

Key findings of the empirical studies

An understanding of attitude formation through elaboration processes facilitates the identification of the circumstances under which persuasive messages can influence public attitudes and behavioral intentions regarding science and emerging technologies. In essence, the objective of this research was to examine the impact of contextual and individual-level factors on attitudes toward emerging technologies within the context of news reporting. To investigate these aspects, this dissertation reported three empirical studies regarding the media influence of *contextual and individual determinants* (study 1), the effects of *message framing* (study 2), and the effects of *source factors* (study 3) on attitude formation towards emerging technologies.

Table 27. Summary of the empirical studies of this dissertation

	Study 1	Study 2	Study 3
Research design			
Between-subject factors	Eight technology issue blocks	Text framing (gain/loss/neutral) Picture valence (positive/negative/no picture) Fully crossed	Gender source (female/male) Age Source (young/ old) Picture (yes/no) Fully crossed Control (no gender, no age, no picture)
Within-subjects-factor	Four technology topics	Five technology topics	Five technology topics
Sample	<i>N</i> = 501 UK, USA, GER Online access panel Respondi & Bilendi	<i>N</i> = 314 UK Online access panel Respondi & Bilendi	<i>N</i> = 649 UK Online access panel Respondi & Bilendi
Main findings			
Subjective knowledge	ICC person: 0.40 ICC tech: 0.14 ICC country: 0.10 + Higher education + TV, print, online news, peer and expert communication		
Subjective relevance perception	Personal relevance perception ICC person: 0.41 ICC tech: 0.07 ICC country: 0.14 + Print, online news, expert communication Societal relevance perception ICC person: 0.43 ICC tech: 0.08 ICC country: 0.10 – Production technologies + Higher education – Print + TV, online news, peer communication, expert communication		
Support		ICC person: 0.38 ICC tech: 0.13 + Loss framing, congruent cond: gain framing/positive picture	

	↑ Subjective knowledge → less support for non-congruent messages ↑ Message valence → more support for non-congruent messages	
Behavioral intentions	ICC person: 0.45 ICC tech: 0.12 ↓ Subjective relevance perception → more behavioral intentions for non-congruent messages	
Message credibility		ICC person: 0.60 ICC tech: 0.10 + Support, behavioral intentions, subjective knowledge, subjective relevance perception
Source credibility		ICC person: 0.63 ICC tech: 0.12 Older scientists + Picture → higher source credibility + Support, behavioral intentions, subjective knowledge, subjective relevance perception

Across the three studies, as shown in Table 27, the findings consistently demonstrated that individual-level differences, such as subjective knowledge and predispositions, played a more substantial role in shaping responses to news reporting on emerging technologies than contextual factors, such as the specific topic or framing of the newspaper stimuli. This is evidenced by the elevated ICC (person-level) values. Thus, 38% to 63% of the variance in subjective knowledge, subjective relevance perception, support, behavioral intentions, and credibility perception was attributable to individual differences. In contrast, ICC values on the technology/topic-level were consistently lower, indicating that only 7% to 14% of the variance could be explained by contextual factors related to the technology or message characteristics. This emphasis on individual-level variation aligns with theoretical perspectives that described audience characteristics as critical moderators of media effects (Brossard & Nisbet, 2007; D. A. Scheufele & Lewenstein, 2005).

Study 1 examined the subjective knowledge and subjective relevance perception of 32 emerging technologies across samples in three countries. In this regard, the findings

of this study revealed that personal characteristics such as media use, education level, age, and gender have a stronger influence on subjective knowledge and subjective relevance perception than differences at the country or technology level. The study descriptively revealed minor variations in subjective knowledge across the emerging technologies investigated, with higher knowledge reported for energy technologies than for other technology groups. Moreover, biotechnologies and digital technologies were regarded as the most relevant in terms of personal and societal concerns. Conversely, production technologies were perceived as less significant, presumably due to their industrial emphasis. A notable finding was that US participants exhibited higher levels of subjective knowledge and subjective relevance perception compared to their counterparts from Germany and the UK. This discrepancy is presumably attributable to the disproportionate influence of the US's substantial technological economy and its pervasive media discourse, which accentuates the pivotal role of technology in fostering growth and competitiveness (National Science Board, 2018; NSF, 2022). Individuals with a university education demonstrated heightened subjective knowledge and perceived technologies as more relevant. In accordance with the extant literature, this finding corroborates the notion that higher education is associated with heightened technological literacy and interest (Drummond & Fischhoff, 2017; Hoekstra et al., 2024).

However, information behavior, particularly media use and interpersonal communication, accounted for the most significant amount of variance in technology perceptions. Consistent with prior research, this finding underscores the pivotal role of media consumption in shaping subjective science knowledge (Brossard & Nisbet, 2007; Nisbet et al., 2002). A positive association was demonstrated among information sources, including television, print news, online news, and interpersonal communication with peers and experts, on subjective knowledge. Furthermore, the consumption of print and online news and communication with experts was found to be positively associated with subjective personal relevance perception. Conversely, television, online news, and both communication with peers and experts exhibited a positive relationship with subjective societal relevance perception.

Online news use has been identified as a significant positive factor in the three outcome variables, thereby underscoring the growing importance of digital channels in informal science education (Davies & Hara, 2017; Jang, 2013). However, frequent exposure to science content, particularly online, may also lead to an overestimation of scientific understanding, contributing to inflated perceptions of knowledge and support for

scientific research despite limited empirical comprehension (Knobloch-Westerwick, Mothes, et al., 2015; Leonhard et al., 2020). A promising direction for future research is to unpack the mechanisms behind the “illusion of knowledge” among frequent consumers of online science content (see for example C.-Y. Park, 2001). Subsequent studies could examine how particular categories of digital content, differing in terms of complexity and credibility, affect both actual and subjective knowledge. Such a discrepancy in knowledge levels could affect decision-making, trust in science, and engagement, necessitating effective science communication strategies that mitigate overconfidence and foster informed public attitudes.

In this regard, study 2 corroborated the notion that there exists considerable individual variability in support and behavioral intentions toward emerging technologies. Specifically, the impact of participant differences surpassed that of exposure to technology-specific issues alone. Experimental manipulations of message framing and picture valence revealed that message effects were strongly influenced by subjective knowledge and subjective personal relevance perception, which are key moderators consistent with dual-process theories of persuasion. Therefore, individuals with higher subjective knowledge demonstrated heightened sensitivity to the congruency between text and visuals. The aforementioned subjects exhibited heightened support in instances where the messages were congruent, that is to say, when the text was positively framed and accompanied by positive imagery. Conversely, non-congruent messages elicited more critical evaluation and rejection, thereby reducing persuasive effectiveness. This pattern aligns with the Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986a), which posits that knowledgeable audiences engage in central-route processing, systematically scrutinizing message consistency and quality. In line with extant research, higher-knowledge-level audiences have been shown to be more attuned to inconsistencies in messages and better able to resist framing cues due to the activation of existing knowledge (Chong & Druckman, 2007; T. E. Nelson et al., 1997).

Conversely, lower subjective knowledge levels were associated with reduced sensitivity to message congruency. It can be deduced from this that participants with limited knowledge placed greater reliance on heuristic processing and evidenced less differentiation in their responses between congruent and non-congruent conditions (Bode et al., 2020; Kahlor et al., 2003). Subjective personal relevance perception emerged as a secondary critical moderator. When faced with messages that were personally relevant to them, participants engaged in more effortful processing and demonstrated a preference

for congruent, well-matched combinations, while exhibiting a rejection of non-congruent messages. However, when personal relevance was minimal, participants demonstrated a tendency to process messages in a more superficial manner. The subjects' behavior indicated a reliance on peripheral cues, including visual tone and simple framing heuristics. This heightened vulnerability to non-congruent messages was observed even in the absence of internal consistency within these messages (Chang, 2002; Maheswaran & Chaiken, 1991). To this end, the underlying mechanisms may be explained by the psychological concept of cognitive dissonance avoidance (Festinger, 1957; Sherman & Gorkin, 1980).

Overall, subjective knowledge and subjective personal relevance perception as individual moderators accounted for an increase in the variance explained by support and behavioral intentions. This observation is consistent with previous research indicating that framing is not solely a message- or context-level phenomenon, but rather, it depends on how the message is processed (Brossard & Nisbet, 2007; Ho et al., 2008; Nisbet et al., 2002). Message framing and visual cues can serve as powerful peripheral heuristics for less-involved or less-knowledgeable audiences. However, they become the target of careful scrutiny for more involved or knowledgeable audiences. These audiences evaluate the consistency of the arguments with their existing attitudes systematically (Maheswaran & Meyers-Levy, 1990; Smith & Petty, 1996).

Finally, study 3 showed that individual differences significantly predict how credible messages and sources are perceived, with newspaper stimuli related effects playing a negligible role again. In sum, the results of the source-credibility study highlighted the predominant role of prior attitudes in shaping credibility perceptions. Moreover, the study demonstrated that visual source cues, such as age or gender, did not play a substantial role in the development of attitudes. However, when combined with a visual presentation of the source, the indication of age for an older scientist resulted in a higher source credibility perception compared to a source without picture. The emergence of this effect may be specifically attributed to the condition in which the older scientist's age was explicitly indicated. It is plausible that the integration of age information and visual representation provided an expectancy-consistent cue for expertise. Consequently, participants may have drawn on stereotypes such as linking age with scientific experience or wisdom (Chaiken & Maheswaran, 1994). However, in this study, source characteristics were found to have a comparatively diminished influence on credibility evaluations in comparison to preexisting beliefs. Prior attitudes have the potential to provide a robust cognitive

framework that filters and interprets incoming information. Therefore, individuals with high issue-specific knowledge demonstrated a reduced reliance on peripheral cues, such as source appearance, when assessing credibility (Wood et al., 1995).

These findings from study 3 are at odds with those from study 2, which revealed that individual differences, such as subjective knowledge and subjective personal relevance perception, influenced the persuasive impact of message congruency between text and visuals. However, both sets of findings align with dual-process theories, such as the Elaboration Likelihood Model (ELM), which posit that under conditions of high involvement or strong prior attitudes, individuals engage in central-route processing. In this case, they rely on internal consistency and message quality rather than superficial source cues (Petty & Cacioppo, 1986a, 1986b). While source cues can influence credibility judgments among less involved or less knowledgeable audiences, their impact diminishes as prior attitudes strengthen and cognitive elaboration increases (Petty & Cacioppo, 1986a, 1986b).

Taken together, the results of the three experimental studies indicate that individual-level variables, such as subjective knowledge, subjective personal relevance perception, are more critical in shaping how people process and respond to media messages about emerging technologies than message features and contextual factors. Therefore, the findings support the cognitive persuasion model's notion that the depth and likelihood of information processing moderate framing effects and credibility judgments (Petty et al., 1995). Nevertheless, further contextual and personal-level variables that were not reviewed in this thesis might also impact how viewers comprehend emerging technologies. This matter will be discussed further in the following sections.

8.2 Theoretical and Methodological Limitations

Expanding the understanding of the effects of science media reporting

Overall, the perspective of media effects has received comparatively little attention in science communication research. Media framing effects are often considered as small in magnitude, particularly with regard to altering attitudes or behaviors, since individuals' existing predispositions and life experiences render them resistant to a single persuasive message (Amsalem & Zoizner, 2020). For highly familiar or polarizing topics, such as abortion, framing effects may be virtually absent (Detenber et al., 2007; Zaller, 1992). However, framing can have a stronger impact when audiences have little prior knowledge

of an issue (Detenber et al., 2007), as was expected with the relatively novel and unfamiliar issue of emerging technologies. Framing studies have often conceptualized frame types as discrete, predefined categories (e.g., conflict, economic, or moral frames), rather than treating framing as a continuous process involving varying emphases and subtle manipulations of message content. This categorical approach may overlook how specific components within a message shape audience perceptions and attitudes. To address this limitation, study 2 investigated which message elements, such as framing tone, textual emphasis, and visual valence, contribute to cognitive and attitudinal responses toward emerging technologies.

While study 2 examined gain and loss framing by varying outcome valence while keeping the initial content about emerging technologies constant, future studies could test emphasis frames, which shape attitudes by making specific risks or other attributes, such as environmental or health concerns, more salient in the message (Luong et al., 2019). Additionally, future research could evaluate how acknowledging opposing viewpoints in media reporting (message sidedness) enhances confidence in attitudes and behavioral intentions regarding emerging technologies (Rucker et al., 2008). In this regard, emphasizing specific risks, such as environmental or public health concerns, can be considered relevant to shaping perceptions and attitudes (Hornig, 1990; Myers et al., 2012). Moreover, considering counter-framing, which opposes an earlier effective frame, could be valuable because audiences often encounter multiple opposing frames in real-world discourse. In this sense, counter-framing aims to undermine or recontextualize dominant frames (Chong & Druckman, 2013).

Examining the integration of arguments and source cues in experimental research designs is also imperative. According to the Heuristic-Systematic Model (HSM), the way individuals process persuasive messages depends on the interaction between heuristic cues — such as source expertise — and the strength or clarity of the message content. This line of research is valuable as it highlights how expectations based on source cues can either contrast with or be assimilated into the evaluation of message arguments. Specifically, when the content contradicts expertise-based expectations (e.g., weak arguments from an expert), individuals exhibit a contrast effect, leading to more critical evaluations. However, when the message is ambiguous, individuals tend to rely more heavily on the source cue itself, resulting in an assimilation effect, where high expertise enhances and low expertise undermines message evaluation (Bohner et al., 2002; Heesacker et al., 1983).

Long-term effects

Because individuals encounter competing frames and new information over time, the effects of a single exposure to a message are often short-lived (Chong & Druckman, 2007). Furthermore, the sleeper effect, where delayed persuasion occurs despite initial discounting, varies with message type and context and tends to be negligible to moderate in impact under high motivation and cognitive ability (Kumkale & Albarracín, 2004). According to Baden and Lecheler (2012), framing effects tend to be brief in duration when the message provides minimal new information or when the relevant knowledge is either inaccessible or highly accessible, thereby rendering the frame redundant. In addition, Matthes and Schemer (2012) also found that framing effects exhibited greater resilience when initial opinions were held with low certainty, and when exposure to competing frames led to opinions shifting in directions counter to the original frame. In contrast, when individuals held strong opinions as a result of initial frame exposure, the framing effects persisted over time.

In consideration of these factors, it is imperative to investigate the long-term implications of the framing process. Doing so is crucial to comprehending the evolution of public opinion in increasingly complex and dynamic media settings, where individuals are confronted with a multitude of messages that may be in discord with one another. An investigation into the factors that contribute to the endurance of specific frames, such as biased processing, selective exposure, and counter-arguing, can provide a more profound understanding of the mechanisms that facilitate the persistence of certain frames while others rapidly lose influence (Brownstein, 2003; Kumkale & Albarracín, 2004). In order to effectively examine the long-term effects of framing and their persistence, research designs such as longitudinal panel studies and repeated-exposure experiments are valuable because they capture attitudinal changes over time and reflect real-world communication environments.

Trust in research and technology misperceptions

While not the primary empirical focus of this dissertation, variables such as research trust and technology misperception represent important complementary attitudinal outcomes that warrant further investigation. Public trust in research institutions and scientific expertise influences the interpretation, acceptance, and response of individuals to messages concerning emerging technologies. Research on misinformation and misperceptions has demonstrated that individuals frequently rely on heuristics, values, and identity cues when

evaluating technological information, rendering them susceptible to frames that align with these predispositions (Hendriks et al., 2016; D. A. Scheufele & Krause, 2019). For instance, messages emphasizing scientific consensus or expert endorsements tend to be more persuasive to audiences that trust science. Conversely, audiences that do not trust science may resist such messages or interpret them as elite manipulation (Bode et al., 2020; Connor & Siegrist, 2010).

In addition, as demonstrated by Brossard and Nisbet (2007), people who trust scientific authority are more likely to support agricultural biotechnology. This phenomenon can be attributed to a variety of factors, including the presence of trusted sponsors and a generally positive view of science. Subsequent studies could investigate the manner in which framing interacts with levels of trust in science and baseline misperceptions to influence attitudes toward emerging technologies. For instance, does the strategic use of risk framing serve to exacerbate misperceptions among audiences characterized by low levels of trust, or can benefit frames, when meticulously designed, effectively rectify erroneous beliefs? Experimental work could test the hypothesis that trust moderates the effects of framing on acceptance of technology (Siegrist et al., 2003). Concurrent survey or panel designs could track whether exposure to consistent frames over time reinforces or corrects misperceptions.

Research design considerations

A central debate in the field of framing typology concerns the distinction between equivalence and emphasis framing (see also chapter 3.2.2). Of particular interest for study 2 was the investigation of equivalence framing (Druckman, 2001a) which examines the impact of different formulations of logically equivalent information, in this case gain versus loss frames on decision-making as illustrated by the well-known "Asian Disease" experiment (Kahneman & Tversky, 1979). Overall, equivalence framing as category offers strong internal validity (D. A. Scheufele & Iyengar, 2014). In light of this context, the adoption of a factorial design in study 2 proved to be of particular value, as it facilitated the concurrent manipulation of gain and loss text-based information, and pictures of varying valence. This approach enabled the examination of both the independent (main) effects and the combined (interaction) effects of these variables on audience responses (see also Mcleod et al., 2022 for a further discussion on design choices). From the perspective of science communication research, this may be of critical importance, as news messages rarely rely on text independently; rather, text and visuals work together to shape audience

perceptions. By employing the factorial approach, a more nuanced and realistic understanding of multimodal message design is facilitated, as evidenced by the demonstration that aligning these components can enhance the impact of the message. It was further demonstrated that these effects may be contingent on factors such as subjective knowledge and topic relevance perception, insights that would not have been attainable without the systematic variation and combination of these elements in the experimental setup. However, a significant limitation of the text framing used as equivalence framing is its reliance on relatively short and straightforward assertions, which may not fully capture the complexity of real-world communication to threaten the external validity of the findings (McLeod et al., 2022).

In contrast to equivalence framing, emphasis framing focuses on which aspects of an issue are highlighted (Druckman, 2001a). On the one hand, emphasis framing offers higher external validity, possibly better reflecting news stories that emphasize different values or concerns. On the other hand, it complicates the isolation of precise causal factors due to its frequent use of varying facts. Critics have posited that this may exaggerate framing's influence, as framing effects are frequently perceived as more pervasive than they actually are. Moreover, many observed outcomes may actually stem from other media effects, such as priming, agenda-setting, or general persuasive messaging, rather than framing per se (Cacciatore, Scheufele, & Iyengar, 2016).

The theoretical distinction between the two concepts has also been considered blurry, as equivalence frames may carry implicit cues or ambiguity, while emphasis framing studies vary in the extent to which they modify factual content (Kühberger, 1998; Luong et al., 2019). As proposed by McLeod et al. (2022), an alternative approach to the conventional understanding of framing concepts as a dichotomy might be to focus on the elements of a message that are subject to manipulation and the manner in which they influence perception. The acknowledgement of the existence of a spectrum in framing could provide a more nuanced and comprehensive understanding of the phenomenon. Future studies could expand the framing effects by combining different methodological approaches, for instance content analysis of equivalence frames and panel data on attitudes toward the issue.

However, although the mixed research designs used in studies 2 and 3 were found to have sufficient statistical power (see chapters 6.2.4 and 7.2.4), the factorial structure with crossed between-subjects factors and an additional within-subject factor (technology topic) resulted in 45 possible stimulus combinations. While these designs offer

comprehensive insights, their inherent complexity may still impede the ability to detect interaction effects. Furthermore, given the absence of pretesting the neutral framing condition in study 2, it cannot be assumed with certainty that participants interpreted it uniformly as neutral. This perception may have been characterized by a sense of vagueness or diminished engagement, which could have resulted in variations in attention or interpretation. Such variability could have introduced additional noise into responses and limit the extent to which the neutral condition serves as a consistent baseline for comparison. However, the control condition without a picture also served as a useful baseline to isolate the impact of visual stimuli, but it also introduced some limitations. The complete removal of images has the potential to result in disparities in the engagement or attention levels of recipients compared to conditions involving pictures, which could lead to confounding results. While it remains improbable to precisely quantify this influence, the standard deviations reported in Table 13 indicate that any observed bias was presumably not systematic. A comparison of response variability across neutral framing, gain and loss framing conditions, pictures of varying valence, and the absence of a control picture indicates that the influence was consistent across conditions.

Furthermore, study 3's design diverged from study 2 due to its emphasis on disentangling the combined and separate effects of demographic cues and visual imagery. Consequently, study 3 necessitated a distinct baseline and control strategy, which differed from the approach employed in study 2, which focused on framing and valence. While the integration of the no-picture condition as a baseline in study 2 was deemed suitable for the isolation of visual effects, its applicability in study 3's social identity context, where textual cues played a pivotal role in the manipulation process, was deemed less optimal. Notably, all eight experimental conditions consistently incorporated textual elements, including information regarding the source of the given information, the scientist's gender and age, and the presence or absence of an accompanying image. Within the experimental groups, the picture presence factor (i.e., the presence of pictures versus the absence of pictures) was fully crossed with gender and age; however, the picture was only manipulated in conditions where gender and age were explicitly provided in the text. In contrast, the control condition is devoid of these contextual cues. As a result, the image's impact could not be separated from the presentation of demographic information; rather, it augmented the existing textual cues by adding a visual dimension.

Accordingly, the observed differences between the control and experimental groups are predominantly indicative of the presence versus absence of social information,

as opposed to the discrete effects of gender, age, or picture presence in isolation. Notwithstanding these limitations, the design offers substantial insights. In the absence of social identity cues, the control condition demonstrated how individuals generally react. Thus, the experimental conditions revealed how the introduction of textual and visual information influenced perception. This layered design captures both the baseline impact of source cues and the enhancing effect of visual imagery. In the interest of refining these findings, future research endeavors could encompass the addition of further conditions that entirely capture the presence and absence of text-based demographic information and pictures. For instance, the use of conditions with text only, picture only, both text and picture, and neither would facilitate a more precise disentanglement of the unique and combined effects of these variables.

Conducting an experimental investigation into the attitude towards a broad range of emerging technologies, including those with varying degrees of familiarity, represents a rare approach in the realm of science communication research. In order to enhance the generalizability and ecological validity of the findings, the decision was made to incorporate a variety of technology-related subjects into the research designs for the three empirical studies. Therefore, the scope of the findings expanded beyond the boundaries of a single technological domain, such as biotechnology or nanotechnology alone. To mitigate potential biases associated with sequence or content, the combinations of the between-subject factors were randomized across five technology topics. By doing so, the effects of order and topic-specific biases were controlled, thereby reducing systematic confounds. In all of the three empirical studies technology topics were treated as a random effect to account for variability across different emerging technologies, thereby improving the generalizability of the results. This approach is contingent upon the assumption that the selected topics represent a more extensive range of technologies (Judd et al., 2012). However, the study did not assess interactions between topic and other variables, such as framing. Furthermore, disparities in participants' familiarity or attitudes toward each technology may still influence responses, signifying that some significant variability could remain unexamined despite statistical controls.

Mediation effects

This research's focus on moderation effects, grounded in dual-process models, emphasized when framing effects occur by examining individual differences in motivation and ability (e.g., central vs. peripheral processing) (Petty & Cacioppo, 1986a, 1986b). While

this approach shed light on how factors like subjective knowledge and subjective relevance perception alter media effects, it overlooked the exact mechanisms of the underlying cognitive processes driving these effects. Future studies incorporating mediation analyses could better explain how framing shapes cognition and attitudes, offering a more complete understanding (see for example Lecheler & De Vreese, 2012).

While numerous studies have posited the mediation of variables in the framing effects process such as partisanship, the accessibility and applicability of key cognitive mechanisms have frequently been assumed rather than empirically tested. Accessibility has been defined as reliance on recently activated considerations (Zaller, 1992), whereas applicability emphasizes the relevance of those considerations to the issue at hand (Price et al., 1997). In order to more effectively validate theoretical models of media framing, future research should prioritize the direct measurement of these mechanisms, such those being obtained through thought listing (Price et al., 1997). Another empirically tested pathway for framing effects is perceived belief importance. Research has demonstrated that exposure to specific frames enhances the perceived significance of frame-relevant considerations, which subsequently influence attitudes (T. E. Nelson & Oxley, 1999). As the existing literature shows, individuals have been observed prioritizing thoughts consistent with prevailing frames (Lecheler & De Vreese, 2012; Vishwanath, 2009).

A growing body of research has indicated the mediating role of affect in shaping how individuals interpret information and form judgments, particularly in the context of science and risk communication (Leiserowitz, 2006; Slovic et al., 2004). Cognitive models of risk perception, in their prevailing form, prioritize analytical reasoning and heuristics such as availability and representativeness (Pachur et al., 2012; Tversky & Kahneman, 1974). However, the affect heuristic (see chapter 4.1.1) posits that emotional responses frequently function as intermediary processes through which information influences perceptions of risk and benefit (Finucane et al., 2000; Slovic et al., 2007). For instance, exposure to messages emphasizing the advantages of a technology (e.g., nuclear power) can provoke positive emotional responses, which subsequently reduce perceived risk and augment perceived benefit. Conversely, information stressing potential harm has been shown to elicit negative affect, which in turn can lead to an increase in perceived risk and a reduction in perceived benefit (Alhakami & Slovic, 1994; Finucane et al., 2000). Empirical findings suggested that affect-laden responses influence both dimensions in a congruent direction, thereby underscoring affect's role as a unifying evaluative filter (Lu, 2016).

Future research could for example explore whether the emotional response, such as fear, elicited by images mediates the relationship between message framing (loss vs. gain) and behavioral intentions. For instance, the combination of fear-inducing imagery with loss-framed sunscreen messages has been demonstrated to enhance fear and bolster intentions to utilize protective measures (Seo et al., 2013). Such a perspective can be applied to the context of emerging technologies, where public knowledge is often limited and individuals tend to rely more heavily on affective cues. Researchers could investigate whether fear-arousing images in loss-framed messages about potential risks, for example AI risks, increase perceived threat and risk-avoidant intentions, such as support for regulation. Moreover, positive images paired with gain-framed messages have the potential to evoke hope or trust, thereby enhancing support and willingness to adopt AI applications.

Measures

A prominent limitation across all three empirical studies of this work is the reliance on self-reported data in the operationalization of the dependent variables. Self-assessment scales are susceptible to various biases, including social desirability, overconfidence, and the underestimation of one's true perceptions (Rosenman et al., 2011). Furthermore, subjective knowledge was measured using a single-item measure consistent with prior research in science communication contexts (European Commission, 2013; Yang et al., 2017). In consideration of single-item measures, a compelling argument can be made that they serve to reduce the participant's overall task load while enhancing the response efficiency (Allen et al., 2022). However, this approach is not without its limitations. Specifically, the measures are not directly comparable to corresponding items that capture the same construct, and they are more susceptible to measurement error (Allen et al., 2022). Subsequent research endeavors potentially could augment this approach by integrating subjective assessments of knowledge with objective evaluations of technology knowledge. Such an endeavor might entail the integration of well-established metrics quantifying factual or "textbook" knowledge, as previously employed in related studies (e.g., Rihn et al., 2021). Integrating both subjective and objective knowledge indicators would promote a more comprehensive understanding of knowledge gaps, overconfidence, and their potential influence on attitudes and behaviors in science communication contexts.

Furthermore, the operationalization of subjective relevance perception differed across the three studies, reflecting varying theoretical emphases and research goals. While

study 1 measured subjective relevance perception as the dependent variable to capture nuanced distinctions rooted in technology perception, this approach aligns with a more exploratory, diagnostic goal: to understand how individuals construct relevance on emerging technologies in terms of their own lives versus broader societal impact. However, studies 2 and 3 aligned more explicitly with classic persuasion theory frameworks. In this paradigm, subjective relevance perception — or issue involvement — is regarded as a crucial determinant of message processing, affecting how individuals attend to and evaluate persuasive communications (Petty & Cacioppo, 1986b). In contrast to the approach of evaluating the relevance of an issue by assigning a rating to it, experimental manipulation of issue involvement can also be achieved in research endeavors by presenting issues as more or less personally relevant. For example, a policy could be described as affecting participants' own neighborhood versus a distant neighbor's to directly test causal effects on message processing and persuasion (Petty & Cacioppo, 1979b; Petty et al., 1983).

Sample selection

All three studies used online access panels, which were provided by Respondi and Bendi. These samples were based on quota sampling employing key sociodemographic variables, such as gender, age, education, and other characteristics, to ensure that the sample proportionally reflected the population or study requirements. However, it cannot be ruled out that sampling bias occurred by not including certain population members. It has been shown that people who join online panels tend to differ systematically from the general population in terms of factors such as personality traits, media use patterns, and general interest in survey participation (Brüggen & Dholakia, 2010). Study 1 included participants from Germany, the United Kingdom (UK), and the United States (USA), while study 2 and study 3 focused on British samples. Despite providing a certain basis for cross-national comparisons, the limited geographic scope and focus on primarily Western populations restrict the generalizability of the findings.

Notwithstanding the valuable insights gained from studies conducted primarily within the European Union and Western contexts, comparative studies evaluating technology perception and media use across a broader range of countries are notably limited (see for example Guenther & Joubert, 2017). This narrow focus risks overlooking critical cultural, social, and political factors that shape public attitudes toward emerging technologies in different contexts. For instance, existing research reveals significant variations

within Europe, with northern countries like Britain, Denmark, France, and Germany demonstrating consistently higher levels of public scientific knowledge than southern countries (Bauer et al., 1994). This intra-regional diversity highlights the need to expand research beyond traditional Western-centric samples and include populations from Asia, Africa, Latin America, and other underrepresented regions. Incorporating these diverse samples could provide a more comprehensive and nuanced understanding of how cultural values, media landscapes, and educational systems influence public engagement with science and technology.

8.3 Implications for Science Communication Research

Defining science communication audiences

Public skepticism toward emerging scientific fields, for example in the U.S. context, has been linked not only to knowledge gaps but also, and perhaps more critically, to individuals' pre-existing values, beliefs, and motivated reasoning (Brossard & Nisbet, 2007; Druckman & Bolsen, 2011). Together, these factors highlight the need to move beyond the traditional deficit model, which assumes that public resistance stems from a lack of information and that providing more facts will foster acceptance and trust (Miller, J., D., 1983; Sturgis & Allum, 2004). As Dietram A. Scheufele and colleagues (2021) contended, effective public engagement with science necessitates a recognition of both the cognitive and value-laden dimensions that shape public attitudes. It is imperative that endeavors that are narrowly focused on "correcting misinformation" or cultivating uncritical trust may inadvertently exacerbate polarization and deepen public skepticism. Corroborating this argument, the present dissertation reveals that individual-level distinctions, including subjective knowledge and preexisting attitudes, function as substantial moderators of message reception. These results underscore the critical importance of audience characteristics in shaping the interpretation and efficacy of scientific communication.

Furthermore, the dissertation's empirical evidence underscores that contextual factors in science communication, such as message framing, the utilization of congruent and accessible visuals, and the presentation of credible sources, interact dynamically with these individual factors. This interplay suggests that effective science communication must be carefully tailored to the audience's informational needs and motivational states. For instance, individuals with higher knowledge levels may respond more strongly to

congruent text-image pairings, while visuals may be more influential for less involved audiences. The necessity for nuanced, audience-centered communication strategies, as opposed to one-size-fits-all approaches (D. A. Scheufele et al., 2021) is therefore reinforced by the presented results.

This implies an understanding of science communication as a socially embedded, interactive process rather than a one-way transmission of facts (Bucchi & Trench, 2021). It is imperative that future science communication studies explore the influence of diverse communication modalities, ranging from traditional outreach to co-creative and playful formats, on attitudes, understanding, and behaviors across various social contexts and audience segments. To this end, experimental approaches remain vital for rigorously testing how communication strategies can bridge knowledge gaps, overcome cognitive biases, and effectively engage motivated publics.

Moreover, the comprehension of an individual's message processing of scientific messages is predicated on the critical interaction between visuals and the accompanying text or spoken language. As Metcalfe (2018) has argued, the role of images in science communication is twofold. Firstly, the role of images is considered in relation to the scientific images themselves. Therefore, the emphasis is on the application of visual aids, such as diagrams, graphics, and other visualizations, within the scientific realm. A subsequent inquiry pertains to the function of images in relation to the visual depiction of scientific findings across various media platforms. Media sources under consideration include academic journals, traditional mass media outlets, and online platforms. The second perspective focuses on images of science and scientists in media, encompassing the portrayal of scientists, the presence of stereotypes in visual formats such as news, television, and social media, and the impact of these depictions on public understanding. These two perspectives are not always clearly distinguishable, as images employed by scientists to elucidate scientific concepts concurrently shape the public's perception of "science." However, both forms of visual science communication are thought to shape people's mental images of science and influence their attitudes toward it (Metcalfe, 2018).

In this dissertation, both perspectives were addressed. Study 2 centered on the utilization of scientific images for the communication of evidence or processes in relation to message framing regarding emerging technologies. In contrast, study 3 investigated how scientists are perceived based on their portrayal in media discussions concerning emerging technologies. The findings of these two studies suggest that visuals in science communication do not merely serve a decorative or supplementary function; rather, they

operate through a multifaceted interaction with text to influence comprehension and attitudes. As demonstrated in the extant research, images become accessible when they are explained and contextualized through accompanying verbal scientific explanations (see also Metcalfe, 2018). Nonetheless, the present empirical studies undertaken in this work have evidenced that, in the context of processing messages involving text and pictures, an individual's motivation and capacity play a pivotal role in forming their attitudes toward emerging technologies.

Furthermore, the results of the empirical studies highlight the complexities inherent in science communication messages and underscore the necessity of incorporating audience background variables into the design and evaluation of persuasive messages. Building on this foundation, Ancker et al. (2006), for example, discussed several key intervening variables that shape how individuals understand and respond to health risk graphs and visual formats. An important factor here may be the educational level, as stronger visual framing and message order effects are exhibited by less-educated viewers, while more mistrust in representations of scientific uncertainty is experienced by them. In this regard, literacy and numeracy are also critical. Even familiar formats, such as bar charts, require instruction for viewers to interpret them, and individuals with less experience can be expected to process information more slowly and less accurately than experts (Trumbo, 1999).

Implications for science journalism

Effective science communication is achieved when thoughtful planning, coordination, and implementation are applied to crafting messages. Professionals who can design and manage the communication process from start to finish are essential. This includes establishing accessible platforms for dialogue, engaging a wide range of participants, delivering clear and accurate information, considering legal and cultural contexts, and systematically gathering input to improve practices (Fischhoff, 2019). The study's findings have several implications for professional science communicators seeking to enhance public understanding and engagement with emerging technologies. First, the significant influence of individual-level factors suggests that communication strategies tailored to personal characteristics, such as education level and information-seeking behavior, could be more effective than one-size-fits-all approaches. Additionally, emphasizing accessible and engaging information through online news media could help bridge knowledge gaps, particularly regarding complex or unfamiliar technologies, such as synthetic biology.

Moreover, the findings underscore the critical role of source credibility in shaping public attitudes. Communicators, including journalists and policymakers, should carefully select and present sources that are credible and align with audience expectations and values. For instance, portraying scientists as knowledgeable, trustworthy, and relatable can increase the perceived legitimacy of scientific information. Conversely, ignoring source characteristics can lead to the alienation of skeptical audiences or the diminution of message impact. Online journalism and digital platforms play a pivotal role in the widespread and rapid dissemination of scientific information. As this research and related studies have shown, the internet plays a crucial role in shaping the public's understanding of science and technology. While this broadens access to scientific content, it also increases the risk of spreading misinformation because there are fewer mechanisms to filter out false or sensational claims. However, individuals must increasingly take responsibility for evaluating the credibility of science-related information independent of external sources (National Academies of Sciences, Engineering, and Medicine, 2017).

Research consistently documents a persistent disparity in knowledge acquisition through science communication transmitted by online media. Individuals with higher socioeconomic status and educational attainment tend to benefit more from these platforms than individuals from less-advantaged groups (Cacciatore, Scheufele, & Corley, 2012; Tichenor et al., 1970). This discrepancy serves to reinforce existing inequities in access to information, civic participation, and engagement with science-related public discourse. By fostering digital literacy, individuals can be equipped with the tools necessary to evaluate sources and content critically, thereby countering the dissemination of misinformation and the emergence of polarization (Ancker et al., 2006; C. Shen et al., 2019). Journalists play a pivotal role in facilitating comprehension of complex scientific information by rendering it accessible to the general public. When used effectively within a structured framework, the underlying studies of this work have shown that visual elements can improve the comprehension and engagement of science communication, especially among audiences with limited knowledge of the issue.

8.4 Conclusion

In light of the rapid advancements in technology and the increasing prevalence of digital media, it is now more crucial than ever to examine the role of media in shaping public perceptions of technological innovations and the implications this has on policy-making, scientific communication, and societal progress. Emerging technologies, such as

CRISPR, offer significant societal benefits; however, they also present potential ethical and social risks that must be addressed. This underscores the necessity for effective science communication to build trust, facilitate stakeholder engagement, and support responsible policymaking (European Commission: Directorate-General for Research and Innovation & Schomberg, 2011; OECD, 2024a). A body of research has demonstrated that public engagement and dialogue can facilitate the resolution of conflicting values, particularly in the context of debates concerning genetic modification (Baik et al., 2022; D. A. Scheufele et al., 2021). Effective risk governance is predicated on the acknowledgement of complexity, uncertainty, and ambiguity in public decision-making (Klinke & Renn, 2010; Renn, 2015). Consequently, science communication models must integrate rigorous scientific inquiry with participatory approaches, thereby ensuring that interpretations of risks and their ethical implications are openly deliberated. Multistakeholder frameworks, which integrate scientists, policymakers, the media, and the public, facilitate transparent and inclusive regulation of emerging technologies (OECD, 2024a; Porcari et al., 2019).

A further examination of the relationship between media coverage and public attitudes toward emerging technologies, where public awareness is often limited, necessitates a focused understanding of the cognitive processes that shape attitude formation (Anderson et al., 2011; D. A. Scheufele & Lewenstein, 2005). The influence of media reporting on public acceptance or skepticism has been demonstrated by numerous studies, which have shown how framing can affect perception and opinion on emerging technologies (Nisbet & Scheufele, 2009; Nisbet et al., 2002). In this particular context, nanotechnology and biotechnology have been the focus of extensive research. Studies have demonstrated how media frames can influence both public understanding and risk perception (Anderson et al., 2014; Besley & Shanahan, 2005; Dudo et al., 2011).

This dissertation made a contribution to the existing literature on science communication by offering empirical insights into the influence of cognitive factors on the formation of attitudes concerning media coverage of emerging technologies. By incorporating the science communication heuristics framework and the cognitive miser perspective (see for example D. A. Scheufele & Lewenstein, 2005), it advanced beyond the conventional understanding of uniform media framing effects. Therefore, by acknowledging the reliance on cognitive shortcuts and existing frameworks in information processing, this approach underscores the necessity of customizing science communication strategies according to these cognitive moderators.

To this end, the evaluation of the effectiveness of science communication through a strategic and evidence-based view is of crucial importance for the development of impactful messages that resonate with diverse audiences. According to Fischhoff's (2013) seminal framework, the cornerstone of effective science communication, the successful implementation of such efforts must involve the navigation of four interconnected tasks: (1) the identification of the most relevant scientific information to inform public decision-making, (2) the assessment of the audience's existing knowledge and beliefs, (3) the design of communication that effectively addresses critical knowledge gaps, and (4) the rigorous evaluation of whether the communication achieves its intended outcomes. To that end, this dissertation comprises three experimental studies, which offer valuable empirical insights that directly align with these tasks and provide starting points for further goals within the context of evaluating the impact on audience's attitudes regarding the issue of emerging technologies.

In this vein, message framing and credibility of the source have been identified as essential factors in media reporting regarding emerging technologies. Furthermore, an investigation was conducted into the existing knowledge and beliefs held by audiences regarding emerging technologies. This was assessed through subjective knowledge and predisposition measures such as media use, education, and ideological orientation. Through experimental testing of various message strategies, including framing, image use, and source presentation, the studies evaluated how these approaches bridge knowledge gaps and influence attitudes. The results revealed that message effectiveness depends heavily on audience characteristics. For instance, congruent messages (where text and images align) were more persuasive for individuals with high subjective knowledge, whereas visual cues played a more significant role for individuals with lower knowledge or subjective relevance perception of emerging technologies. These findings underscore the importance of tailoring communication strategies to align with the informational and motivational needs of different audience segments.

Building on this, communication objectives can be conceptualized as outcomes influenced by specific communication tactics that affect goal-oriented behaviors. Key objectives include changing beliefs, such as scientific understanding and evaluative attitudes. Behavioral goals vary in specificity, ranging from concrete actions, such as voting, to more abstract goals, such as considering evidence or accepting scientific decisions (Besley & Dudo, 2022). Integrating these objectives into communication design strengthens the alignment between message strategies and desired public outcomes. As such, the

empirical studies presented here offer a foundation for implementing these principles and provide concrete implications for developing more responsive, targeted, and impactful science communication strategies.

Along with methodological improvements, it is crucial to critically examine the broader institutional and normative objectives of science communication. Questions arise about which outcomes are valued, who defines them, and whether science communication practices risk embedding exclusionary norms that marginalize certain groups of people (E. A. Jensen, 2014). Moreover, shifting from deficit to participatory models in science governance is challenging due to entrenched communication and institutional practices that constrain transformative engagement efforts (D. A. Scheufele et al., 2021). Consequently, despite its prominence, public engagement's influence on policy remains inconsistent, depending heavily on the process quality and decision-makers' genuine integration of public input (European Commission: Directorate-General for Research and Innovation and Billgren Askwall, C., 2024). A shift toward more open and participatory models of engagement that emphasize deliberation and inclusivity has been suggested as an alternative approach that would be consistent with broader democratic and ethical considerations (Macq et al., 2020).

These perspectives are important for science communication because they suggest that efforts to improve public scientific literacy are crucial for enabling more informed engagement with scientific issues. At the same time, science communicators must recognize the role of heuristics in how people process information and make decisions. A dual focus on scientific literacy and heuristics can help science communicators design more effective strategies to make scientific content accessible and engaging for different audiences (National Science Board, 2018). In the field of emerging technologies, this can be used to explain why people may rely on trusted figures' advice or others' experiences when making decisions about using technical applications (Bingaman et al., 2021). Similarly, in environmental communication, this perspective can be adopted to grasp how individuals form opinions on matters such as climate change, frequently relying on social norms, emotional responses, or political cues rather than a profound comprehension of the scientific principles involved (Leiserowitz, 2006).

Effective science communication is required to move beyond the transmission of information to address the social, ideological, and emotional factors that shape individuals' perceptions and responses to scientific messages. Media channels and formats play a substantial role in this process, as they disseminate scientific information and frame it in

ways that resonate with or challenge audiences' existing values and beliefs. In order to establish trust through media channels, it is essential to facilitate genuine dialogue, acknowledge public concerns, and respect diverse viewpoints. Instead of merely disseminating unidirectional messaging, it is crucial to engage in a reciprocal exchange of ideas. Fostering community engagement in a manner that is both respectful and transparent, both within media content and through broader communication initiatives, is imperative for cultivating informed, critical, and trusting public engagement with science.

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Appendix: Literature Overview

Study	Context	Research design	Moderating/ Mediating variables	Dependent variables	Results
<i>Media framing effects</i>					
Cobb (2005)	Nanotechnology Framing theory	10 conditions: Frame type x sidedness; Control group, no framing; Conservative humanist, one-sided; Conservative humanist + Health risks, one-sided; Conservative humanist + Multiple risks, one-sided; Cornucopian, one-sided; Cornucopian + health benefits, one-sided; Cornucopian + multiple benefits, one-sided; Conservative Humanist vs. Cornucopian, two-sided; Health risks vs. health benefits, two-sided; Multiple risks vs. multiple benefits, two-sided		Risk and benefit perception (risks of nanotechnology greater than, equal to, or less than benefits) Trust industry officials to minimize risks to humans Emotion (hope, anger, worry)	Consistent framing effects, though opinion changes were small Specific risk/benefit frames were more influential than general science belief frames Risk frames were slightly more powerful than benefit frames Two-sided frames generally failed to change opinions
Lu (2016)	Environmental crisis Framing theory Discrete emotion approach	3 (emotional appeal: sadness, hope, or neutral) $\times$ 2 valence: gain or loss) Between-subjects factorial design	Emotions	Behavioral intentions Information seeking intentions	Sadness appeal effective in promoting information seeking and behavioral intention of policy support Sadness appeal more effective when paired with gain framing Hope appeal to have greater impact when combined with loss framing

Dixon et al. (2015)	Autism-vaccine link Exemplification theory	Control article; Balanced article; Balanced with weight-of-evidence article (text only); Balanced with weight-of-evidence article + group of scientist exemplar photograph; Balanced with weight-of-evidence article + single scientist exemplar photograph	Deference to scientific authority	Personal beliefs Perceived perceptions of scientists	Including weight-of-evidence information fostered more accurate beliefs about an autism-vaccine link, for individuals with favorable pre-existing scientific views Perception of what scientists believe mediated the effect of balanced information on personal beliefs, the false balance article induced belief about the state of expert opinion, which negatively influenced personal beliefs that vaccines did not cause autism
Dahmen (2011)	Stem cell debate Framing theory	Photographic framing political (President Obama signing stem cell legislation), medical (person in a wheelchair because of a spinal cord injury), scientific (scientist conducting research in a laboratory), and ethical (protesters praying and holding anti-stem cell research signs) Pretest-posttest experimental research design, eye-tracking data		Attitude Attention to the message	No significant effects between experimental condition and participant perception of the predominant issues in the stem cell research debate Photographic framing did have a significant effect on participants' visual attention to the given photograph

Anderson et al. (2014)	Nanotechnology Framing theory Incivility	Neutral blog post, tone of user comments (civil or uncivil) x valence (risks or benefits) Between-subjects-design	Religiosity Political ideology Media use Issue familiarity	Risk perception	Individuals who do not support nanotechnology, those who are exposed to uncivil deliberation in blog comments, are more likely to perceive the technology as risky than those who are exposed to civil comments Highly religious individuals are more likely to perceive nanotechnology as risky when exposed to uncivil comments compared to less religious individuals exposed to uncivil comments.
Seo & Dillard (2019)	Travel Tablet PC Appraisal process model of persuasion	2 (valence framing: gain or loss) x 3 (image: matched image or mismatched image or no image) x 2 (message topic: travel or tablet PC) x 2 (message order: travel message first or: PC message first) Mixed factorial design	Perceived message valence Emotional response Cognitive response	Behavioral intentions	Effect of matching in the gain-framed matched conditions, but not in the loss- framed conditions Influence of framing and image on persuasion mediated through judgments of message valence
Lee & Park (2013)	Korea-U.S. FTA (Free Trade Agreement) Prospect theory	2 (valence framing: gain or loss) x 2 (framing of contingency: certainty or uncertainty) x 2 (message anchoring: self- generated anchoring or experimenter-provided anchoring) Between-subjects-design	Issue Involvement	Support	Loss-framing message more effective than the gain-framing message in influencing agreement on the issue For experimenter-provided and self- generated anchor inducements, the participants with experimenter-provided anchor values are more likely to agree with suggestions in messages than those with self- generated anchor values

Bingaman et al. (2021)	Artificial intelligence Framing theory	4 (text condition: no frame or social progress or pandora's box frame or both frames) x 4 (image condition: no image or real-world virtual assistants or real-world personal robots or menacing AIs from popular movies) Between-subjects-design	Support	Social progress framing induced greater support for AI than Pandora's box frame Images interacted with textual frames, support for AI was greatest among respondents who received the benign, mundane images of Alexa and Siri with the social progress frame and lowest among those who received the menacing images of Skynet and Ultron with the Pandora's box frame (evidence for congruence message effect)
Dorison et al. (2022)	Covid-19 Framing theory	2 (message framing: loss or gain x 3 (recommendation: version 1 or version 2 or version 3) Between-subjects factorial design	Attitude Behavioral intentions Information seeking Anxiety	Loss-framed messages increased self-reported anxiety among participants cross-nationally with little-to-no impact on policy attitudes, behavioral intentions, or information seeking relevant to pandemic risks

Lazard & Atkinson (2014)	Recycling GMOs Elaboration- Likelihood-Model (ELM)	Study 1: 2 (message format: text-based or infographic) x 2 (learning preferences: verbal or visual) x 2 (visual literacy: high or low) Issue recycling Between-subjects design Study 2: 3 (content format: text-based or infographic or visual-based) x 2 (learning preferences: verbal or visual) x 2 (visual literacy: high or low) Issue GMOs Between-subjects design	Elaboration	Study 1: Individuals exposed to the infographic reported greater elaboration than individuals exposed to the text-based message. Regardless of learning preference, individuals exposed to the infographic experienced higher elaboration than those exposed to the text-based message. Individuals who identified as having low visual literacy reported higher elaboration for the infographic when compared to the text-based message. Study 2: Individuals in the infographic condition reported greater elaboration than participants in the text-based message or the visual-based message conditions. Verbal learners shown the infographic had a greater elaboration compared to text-based or visual-based messages.
Hart & Feldman (2016)	Climate change perception	5 (imagery: solar or flood or march or smoke or no image) × 3 (text: impacts or actions or both) 15-cell, fully crossed design	Behavioral intentions Ecological beliefs Efficacy Issue importance	Use of solar panel imagery increased perceptions of efficacy related to climate change. News stories that discuss actions that can be taken to address climate change increased perceptions of efficacy. Democrats having greater perceptions of efficacy.

Thacker et al. (2020)	Genetically modified foods Persuasion	4 (Refutation, misconceptions: statement 1, statement 2, statement 3, statement 4) x 3 (valence: advantages of GMFs or disadvantages of GMFs or advantages and disadvantages)	Attitude Knowledge Epistemic emotions	Individuals in the both pro-and-con-GMF condition held more positive attitudes towards GMFs compared to individuals in the con condition Individuals in the both pro-and-con-GMF condition had fewer post-test misconceptions compared to the con-GMF condition Individuals with more positive prior attitudes in the pro-GMF and both pro-and- con GMF conditions significantly changed more misconceptions whereas individuals with more positive attitudes in the con-GMF condition maintained their misconceptions
Knobloch-Westerwick et al. (2015)	Fracking Genetically modified foods Biofuels Nanotechnology Exemplification theory Confirmation bias	2 (exemplar or numeric) × 2 (supporting or opposing technology) Within-subjects design	Numeracy Trait empathy Attitude	Validation of the confirmation bias: exposure to attitude-consistent messages emerged as a significant predictor for attitude shift Influence of topic on effects, for topics fracking and biofuels Influence of attitude-consistent numerical messages on attitudes Attitude-conforming numerical and exemplary messages influence attitudes towards fracking and nanotechnology, for attitude-conforming exemplary messages influence of biofuels Interaction: participants with higher trait empathy devoted more time to exemplar messages, while participants with higher numeracy spent less time on exemplar Messages, topic as within-group factor did not affect these patterns

Druckman & Bolsen (2011)	Carbon-nanotubes Genetically modified foods Framing theory	Carbon nanotubes frames (energy or costs /availability (pro) or potential health or risks (con) GM foods (combating world hunger (pro) or biodiversity (con) x fact (without fact or with fact)	Support	Negative conditions uniformly displayed larger effects than the positive conditions No additional effect of facts in frames on opinions on emerging technologies Frames or facts alone with influence on opinions Correlation between originally measured opinion and later measured assessment of technology perception on effectiveness of pro and contra facts of technologies (e.g. being against nanotechnology in first study is associated with higher effectiveness rating of negative facts) (biased processing) No polarization effect on attitudes
Schütz & Wiedemann (2008)	Nanotechnology Framing theory	3 (benefits: health or economic or environmental) x 2 characteristics of enterprises (large multinational enterprises or small and medium-sized enterprises) Factorial Design	Risk perception	Advantages of nanotechnology without influence on risk assessment Benefits of nanotechnology without influence on assessment probability of risk scenarios If smaller companies were seen as benefiting from nanotechnology, led to assessment of lower probability of risk scenarios
Stewart et al. (2008)	Stem cell research (embryonic or adult) Framing theory Dual-process models	Framing (scientific progress or economic prospects or political conflict) Between-subjects design	Participants' motivation and ability to process the text Perception of ethicality Credibility Usefulness of stem cell research	Participants perceived adult stem cell research to be more ethical and credible than embryonic stem cell research in a political conflict frame Science majors attributing greater usefulness to stem cell research than did nonscience majors, deference to science authority is as heuristic particularly influential on science majors

Seo et al. (2013)	Health issues (flossing, sunscreen) Prospect theory Persuasion theory	2 (valence framing: gain or loss) $\times$ 2 (image: image or no image, balanced in terms of outcome extremity) $\times$ 2 (health issue: flossing or sunscreen) $\times$ 2 (order of presentation) mixed factorial design	Cognitive response Fear	Attitude Behavioral intentions Perceived message effectiveness	The loss frame + image condition generated an unfavorable dominant cognitive response and may have induced reactance Addition of an image to the loss-framed messages about sunscreen produced significantly more fear
Frewer et al. (1997)	Food risks Elaboration-likelihood-model	2 (hazard type: high, food poisoning or low, excessive alcohol use) $\times$ 2 (source credibility: high, medical doctors or low, government) $\times$ 2 (persuasive strength statement: low or high) Full-factorial-design	Need for cognition	Risk perception Perception of factuality Perception of information relevance	Medical sources were rated as being more expert and knowledgeable about the risks, and as having greater freedom to present information to the public Information about alcohol use from the government was perceived to be less factual than that from the medical source Perceptions of information relevance were less for excess alcohol use overall Persuasive content was influential in determining perceptions of overall information relevance, with persuasive information was seen as more relevant than non persuasive information
Anderson et al. (2013)	Nanotechnology	Nanotechnology definitions: applications (beneficial, the targeted delivery of drugs, risky, nearly invisible surveillance devices) or risks and benefits or combination of both factors	Science education	Support Interest in more information	Support for nanotechnology increases when introduced to nanotechnology in the context of applications Exposure to a definition of nanotechnology highlighting the risks and benefits encouraged interest in more information about nanotechnology Definitions highlighting risks resonate more among respondents without a degree in science

Tal & Wansink (2016)	Medication efficacy Persuasion	Study 1: Information new medication: graph or no graph Study 2: Experimental (graph) condition: graphical representation of the data, graph cutoff at 0% incidence or graph cutoff at 50% incidence Control condition: same textual information as in Study 1, with an added sentence explicitly stating "Incidence of illness drops from 83% to 63% with the medication," mirroring the graphical data Study 3: Formula condition: scenario describing a drug, including a fictive chemical formula (C ₂₁ H ₂₉ FO ₅) or non-formula condition: same scenario without the chemical formula Between-subjects-design Online panel (study 1), campus population (study 2), general population (study 3)	Belief in science	Perceived effectiveness medication	Study 1: With graph, medication was rated as more effective than with text information alone, majority in picture condition believed that medication reduces illness Study 2: With graph, medication was rated as more effective Belief in science moderated effect of graph on effectiveness rating, graphs increased persuasion to greater extent for people who expressed a strong belief in science Study 3: Assessment of duration of effect of the medication, with formula longer assessment, elements that appear scientific (formula) enhanced the persuasion of the message

Shen (2004)	Stem cell research Oil drilling Framing theory Schema theory	2 (message framing, stem cell research: ethical frame or benefit frame) x 2 (message framing, oil drilling: economic frame or environmental frame Mixed-factorial-design, issues within subject factor, frames between subject factor	Issue schemas	Attitude Issue relevant thoughts	Benefit frame condition led to more support of stem cell research and benefit-related thoughts than the ethical frame Economic frame condition led to more support and frame-related thoughts for oil drilling than the environmental condition Individuals were more likely to activate frame-relevant thoughts and change attitudes when news frames reasoned with their issue schemas Interaction between issue schema and news frame, ethical frame interacted with ethical schema on ethical thoughts on stem cell research compared to benefit schemas Benefit schematics expressed more support for stem cell research for ethical and benefit frames Economic frame and economic schemas interacted on economic thoughts compared to environment schemas Economy schematics were more supportive of drilling Age, political ideology, issue knowledge significant predictors of attitude toward stem cell research

Gustafson & Rice (2019)	Climate change GMO food labeling Occupational hazards of operating vibrating machinery Framing theory	3 (Issues: climate change or GMO food labeling or occupational hazards of operating vibrating machinery) x 5 (uncertainty frame: deficient or technical or scientific or consensus or control condition) Between-subjects design	Prior issue position	Claim belief	Claim belief and credibility perceptions were slightly lower in response to a consensus uncertainty frame compared with the control and compared with other uncertainty frame types, effect was observed in climate change and vibrating machinery conditions but not in the GMO condition
Huang et al. (2019)	Recycling Framing theory	2 (valence framing: gain or loss) x 2 (reference point: self or other) x 2 (modality: text or infographic) Between-subject design		Environmental concern Behavioral intentions Perceived benefits/harms to self Perceived benefits/harms to others	Three-way interaction effects among message framing, reference point, and modality were found perceived harm to self and perceived harm to other When paired with infographics and other- referencing point, loss-framed messages more effective than gain-framed messages in levels of perceived harm to self Hardly any significant effects of message framing and reference point were found when using text Negative association between the self-other gap in perceived harm and recycling intentions
Gantiva et al. (2021)	Covid-19 Framing theory	2 (valence framing: gain or loss) x 2 (content: health or economy) Both-within-condition design		Intentions of self- care behaviors Perceived efficacy to motivate others to perform self-care behaviors Perceived risk Perceived message strength	Gain-framed messages were more effective to generate motivation to engage in self-care behaviors and were perceived as stronger Messages focused on health and with a gain- frame were generally perceived as stronger than both loss-framed health messages and gain-framed economics messages Loss-framed health messages were judged as better to communicate risk

Reinhard et al. (2007)	Organ donation Framing theory	Loss frame or gain frame Prior attitudes assessed before exposure to one of the two message conditions Between-subjects design	Prior attitude Attitude Behavioral intentions Message reaction Level of psychological reactance (study 2, study 3) Thought-listing (study 2) Interest in additional information (study 3)	Study 1 : gain-frame messages provided more positive message reactions and greater behavioral intentions compared to the use of loss-frame messages When controlling for individuals' preattitudes, the difference between means was statistically significant for message reactions (2% variance explained) Study 2 and study 3: Psychological reactance acted as a mediator in the relationship between framing and message reactions Study 3: Gain-framed messages produced lower levels of psychological reactance and manipulative intent and more positive message reactions than loss-framed messages Loss-frames were associated with perceived greater manipulative intent and greater reactance than gain framed messages

Manca et al. (2019)	Sustainable transport Elaboration- likelihood-model	2 (argument quality: strong or weak) x 2 (source Expertise: low or high) x 2 (anticipated emotions: positive or negative) Between-subjects design	Issue involvement	Reaction time assessment Behavioral intentions Attitude Past behavior	Implicit Attitude toward sustainable transport was higher in the negative compared with the positive emotion condition Higher levels of personal involvement were associated with higher levels of implicit attitude when the source was non expert, whereas higher levels of personal involvement were associated with lower levels of implicit attitude when the source was expert Higher levels of personal involvement were associated with higher levels of implicit attitude when the argument was strong and higher levels of personal involvement were associated with lower levels of implicit attitude when the argument was weak

Luong et al. (2019)	Fracking Renewable energy Framing theory Motivated reasoning	2 (issue: fracking or renewable energy) $\times$ 2 (argument: pro or anti) $\times$ 2 (frame: liberal or conservative) Video stimulus Between-subjects design	Ideology	Attitude Policy support Behavioral intention	Support for the promoted policy was higher when information is framed in ideologically congruent ways than when it is not, regardless of the topic or the message stance Pro-renewable energy articles were associated with greater favorability among conservatives when the science information was framed to be congruent with conservative values than when the same information was framed to be congruent with liberal values Only for renewable energy, attitude was a significant mediator in the relationship between emphasis frame and behavioral intention, when reading an article whose stance is congruent with participants' own ideology (liberals reading pro-renewable energy articles and conservatives reading anti-renewable energy articles), the frame had significant indirect effects on behavioral intention via attitude For liberals, reading the pro-issue liberal-framed article led to higher behavioral intentions in support of renewable energy; and for conservatives, reading the anti-issue conservative-framed article led to lower behavioral intentions

Powell et al. (2015)	Political conflict central African republic (CAR) Framing theory	2 (image frame: obligation or risk) x 3 (text frame: obligation or risk or control) Factorial design	Issue knowledge	Support Behavioral intentions Emotions	For image-alone conditions, participants reported higher support and behavioral intentions for intervention in the CAR for an obligation image compared with a risk image When presented alone, the text frames did in fact affect participants' support for intervention, but only for those with high issue-specific knowledge When images and text are combined, the frame carried by the text influences opinions toward military intervention, regardless of the image frame The image frame determines participants' behavioral intentions, particularly the intention to donate, irrespective of the text frame Indirect effects of emotions on framing effects stronger for images than text for both the image/text-alone conditions and image-text combinations.

Frewer (1999)	Genetic engineering Elaboration-likelihood-model	2 (risk relevance: high or low) × 2 (trust information source: high, consumer organization or low, government) × 2 (perceived persuasive information: high or low) Full factorial design	Elaborative processing (thought-listing) Need for cognition	Attitude	When personal relevance was high, high persuasiveness led to greater rejection of the use of animals in both food production and agriculture Information which was both high in personal relevance and low in persuasiveness was most likely to result in reduced rejection of genetic engineering applied to animals for either food or agricultural purposes Respondents who exhibited increased thought listing following the information intervention tended to exhibit thoughts which expressed concern about the development and application of the technology If the information was low in persuasiveness, greatest trust was observed when it was high in personal relevance and attributed to the government, or low in personal relevance and attributed to a consumer organization

Lee and Cho (2022)	Green advertising, print advertising for laundry detergent Framing theory	2 (message frame: gain-framed or loss-framed message) x 2 (image: positive or negative) Between-subjects design	Issue involvement	Attitude Purchase intentions	Main effect of message framing: the gain-framed advertising resulted in stronger advertising attitudes than the loss-framed advertising message Main effect of image valence: positive advertising image showed stronger responses on attitude and purchase intentions than the negative advertising image Incongruent gain-framing with negative-image advertising resulted in less favorable advertising attitudes and brand attitudes than congruent gain-framing with positive-image advertising Incongruent loss-framing advertising messages with positive images were more effective than the congruent condition with negative image When consumers were less involved with an issue, they had more negative advertising and brand attitudes toward a gain-framing message with a negative image than those who had a high issue involvement

Liu et al. (2021)	Automated vehicles Framing theory	Study 1: Vehicle names: intelligent vehicles, automated vehicles, autonomous vehicles, driverless vehicles Study 2: L5 vehicles names: Fully intelligent vehicles, fully automated vehicles, fully autonomous vehicles, fully driverless vehicles, and driverless vehicles	Trust Perceived benefit Perceived risk Positive affect Negative affect Behavioral intentions	Study 1: Respondents placed higher trust in intelligent, automated, and autonomous vehicles compared with driverless vehicles More benefits were perceived of autonomous and intelligent vehicles Intelligent, automated, or autonomous vehicle evoked higher positive affect, an intelligent, automated, or autonomous vehicle evoked (marginally) lower negative affect Indirect effects of names on behavioral intention through trust, perceived benefit, and positive affect Study 2: Driverless vehicles led participants to perceive (marginally) more benefits compared with fully automated and autonomous vehicles Indirect influence on behavioral intention through trust and positive affect

Karpinska-Krakowiak et al. (2023)	Advertising emerging technologies (robot vacuums, VAC, electric car, EVO) Persuasion	2 (argument: abstract or concrete) × 2 (narrative or non-narrative ad) Study 1: matching effect using an established technology product at the majority stage of adoption (robot vacuum cleaner) Study 2 and study 3 dis-matching effect, emerging technology product at the introductory adoption stage (electric cars) Study 3 replication of study 2, polish sample instead of English speaking sample Factorial between-subject design	Transportation	Purchase intentions Psychological temporal distance	Study 1: positive effect of narrative design on transportation, which subsequently had a negative effect on temporal distance toward a robotic vacuum Positive effect of transportation on persuasion, as participants became more immersed in the presented story, they perceived the advertised product as temporally closer Matching effect: interaction effect between temporal distance and argumentation type on purchase intentions, when the temporal distance was low, concrete arguments generated higher purchase intentions than abstract ones, whereas when the temporal distance was high, abstract arguments resulted in more favorable purchase intentions than concrete ones Study 2 and study 3: Positive effect of narrative design on transportation, negative effect of transportation on temporal distance toward electric cars Positive effect of transportation on persuasion, participants who read the narrative ad immersed in the story Interaction effect between temporal distance and type of argumentation on attitudes toward the message, when the temporal distance was low, abstract arguments generated more positive ad attitudes than concrete ones, when the temporal distance

Kreps (2014)	Unmanned aerial vehicles (UAVs, drones) political conflict Framing Theory	2 (IHL compliance: distinction or proportionality) x 2 (legal authorization: domestic or international) Factorial design	Support	Information on international humanitarian law for both distinction and proportionality with negative effect on support of the drone strike program
Palm et al. (2025)	Artificial intelligence (AI) Framing theory	Control condition x pro-condition x anti-AI condition	AI impact beliefs Attitude Trust in science	Exposure to the positively framed message increased beliefs that future advancements in AI would lead to positive impacts in these areas Exposure to negatively framed messages increased perceptions that future AI advancements would have negative impacts Exposure to the positive frame caused respondents to view the benefits of AI's development outweighing the risks Exposure to negative frames led respondents to express the opposite view that the risks of the development of AI outweigh its benefits Exposure to the positive message increased support for the development of AI Exposure to the negative message decreased support for AI's future development Exposure to the negative message decreased trust in science

<i>Source effects</i>					
Study	Context	Research design	Moderating/ Mediating variables	Dependent variables	Results
Knobloch- Westerwick et al. (2013)	Role congruity theory	Abstracts ICA annual conference 2 (research area neutral-typed abstracts: two female authors, or two male authors) x 2 (female- typed abstracts: two female authors or male authors) x 2 (male-typed abstracts: one with two female authors or one with two male authors Six of abstracts used as distractors (female and a male author, with author sequence and research areas), counterbalanced, Two distracter abstracts from gender-neutral research areas and one from a male-typed area presented as single-authored by a male or with four authors (two females and two males, with genders alternating in the author sequence)		Abstract ratings Gender role attitudes Attention to author information Familiarity	Abstracts from male authors were associated with greater scientific quality than abstracts from female authors The perceived scientific quality of a research contribution depended on both author gender and research topic Abstracts on male-typed topics received significantly higher ratings if they were associated with male authors as opposed to female authors Abstracts associated with male authors received significantly higher ratings if they pertained to male-typed topics as opposed to female-typed topics Female authors evoked greater collaboration interest if they worked on female-typed topics than gender-neutral topics Male authors induced greater collaboration interest if they worked on male-typed topics compared to female-typed or gender-neutral topics Stronger support for gender equality led to higher ratings of perceived quality of female authors' contribution

Flanagin & Metzger (2003)	Online source credibility	Two personal web sites, female or male name and photographic images of the individuals on the sites	Issue salience Web experience Participant gender	Credibility	Males found both of the web sites to be more credible than did females Male and female participants differed significantly in age, education, income, and experience with the internet. Males rated the credibility the message credibility on either of the websites to be significantly higher than did females Women visiting the female site found the site overall to be significantly less credible than men Women visiting the female web site found the target story (message) to be significantly less credible than men
Bode et al. (2020)	Genetically modified food (GMFs) Online source credibility	Twitter feed corrective response to an online meme promoting misinformation about scientific consensus on GMF safety 2 (misinformation with no responses or correction with reply by PEW research center x 2 (response with popularity cues in the form of likes: yes or no) Pre-posttest design		GMF misperceptions GMV avoidance behavior Organizational credibility	Correction led to significantly higher perceptions of scientific consensus as compared with the misinformation-only condition in the posttest Indirect effect of correction on GMF misperceptions for those with moderate or high initial misperceptions Those who initially held moderate or high misperceptions about the level of GMO consensus report that they are less likely to avoid GMF after seeing a correction as compared with misinformation only Adding likes to the Pew correction did not lead to more accurate assessments of the scientific consensus on GMF, did not reduce misperceptions, did not impact evaluations of organizational credibility

Weibel et al. (2008)	Television news Source credibility	2 (gender of the newscaster: male or female) x 2 (age of the newscaster: 40 years or >40 years) x 2 (gender of the subject: male or female) Factorial design	Credibility	Messages by female newscasters were evaluated as being more credible than messages read by male newscasters Male newscasters were perceived as being more credible than female newscasters The age of the newscaster had no effect on the perceived credibility of the message or credibility of the newscaster Interaction effect between gender and age of the newscaster: older newscasters were perceived as being more credible if they were male than if they were female Younger newscasters were perceived as being almost equally credible irrespective of whether they were men or women

Ozer et al. (2023)	Experts political media Role congruity theory	Study1: 3 (expertise: high or low or control) x 3 (author: woman-pro or man-pro or control) x six political issues: the health care birth control mandate (birth control), paid parental leave (parental leave), gender-based wage discrimination (wage), automatic voter registration, military drone strikes on foreign combatants (drone strikes), international trade tariffs (tariffs) 6 sets of headlines Selection experiment Within-subjects design Study 2: 2 (author: woman-pro or man-pro x 3 (expertise: high or low or control pro-author) x 2 (In-party or out-party pro-author) x six sets of headlines Within-subjects design	Article selection Credibility author	Study 1: Respondents found high-expertise sources to be more credible relative to the control Respondents perceive low-expertise sources to be less credible relative to the control with no expertise cues When given no expertise cues, respondents find men to be more credible than women Woman news sources were viewed to be 6.2 percent less credible than equivalent men Respondents select women 3.3 percent less often than men Respondents are 8.1 percent more likely to select a woman source in the high-expertise treatment relative to the control with no expertise cues Study 2: Respondents were 12.8 percent more likely to select an in-party source relative to an equivalent out-party source Respondents chose high-expertise sources (6.7 percent increase in selection) and less often chose low-expertise sources (7.8 percent decrease in selection) relative to the control High-expertise cues increased selection of out-party pro-authors, this effect did not vary based on gender cues

Armstrong & Adamson (2021)	Perception of environmental scientists Gender bias	Interview text (same for all conditions) 2 (2 scientists each gender name text and photo: male or female) Sample: Climate scientists' peers	Scientists' attributes	Condition male 2 was rated as significantly higher on science attributes (such as objective and impartial) than condition female 1 Female participants rated the female scientists significantly higher than male participants did for the perception of being self-controlled Male participants rated the female scientists significantly higher than female participants did for the attributes biased and dramatic Female participants rated the male scientists (MC) significantly higher than the male participants did for the perception approachable and expressive
Greve-Poulsen et al- (2023)	Experts' political media Gender bias	2 (topics: euthanasia or entrepreneurship x 2 (issue expert: professor critical towards euthanasia or professor critical on stimulating entrepreneurship) x 2 (gender expert: female or male)	Issue opinion Communicator competence	Respondents in the euthanasia experiment had a higher assessment of the competence of the experts than respondents in the entrepreneurship experiment No statistically significant effects of expert gender on policy opinion or perceived competence Perceptions of male and female experts' competence were not moderated by the audients' own genders

Paul et al. (2022)	News credibility Gender bias	Study 1: 2 (reporter gender: male or female) $\times$ 2 (source gender: male or female) $\times$ 2 (issue gender: workplace sexual harassment (feminine issue) or military drones (masculine issue)) Factorial between-subjects design Student sample Studies 2 and 3: 2 (reporter gender: male or female) $\times$ 2 (source gender: male or female) $\times$ 2 (issue gender: reproductive rights (feminine issue) or veterans affairs (masculine issue) or government corruption (neutral issue)) Study 2: adult sample Study 3: student sample and adult sample	Reporter credibility News outlet credibility News-is-for-me perceptions (study 2 and study 3)	Across three studies and four samples, little evidence for differences in credibility perceptions of a reporter or a news outlet based on the gender of a reporter, the gender of the source, or the gendered nature of the issue Study 1: Reporter credibility was higher when stories covered a feminine issue than a masculine issue, news outlet credibility was higher when stories covered feminine issues compared with masculine issues Study 2: Audiences tend to perceive both reporters and their media outlets as more credible if the news story covers a masculine or neutral issue than a feminine issue, relative to the perceived credibility of male journalists reported by male readers, female reporters were rated significantly higher by female readers, male readers exhibited a significantly lower attachment to feminine issues than female readers Study 3: Feminine-issue stories written by female reporters, were rated significantly higher on news-is-for-me perceptions than the masculine-issue stories written by male reporters, students and adult respondents tended to perceive reporters and news outlets as more credible if the news story covers a masculine or neutral issue than a feminine issue, differences between female readers of

Gheorgiou et al. (2017)	Facial appearance scientists	Study 1: faces random sample of profile pictures from physics and genetics departments of the top 200 US universities. Study 2: faces random sample from biology and physics departments of UK universities, weighted by number of scientists submitted to the 2014 Study 3 and Study 4: text or video format, eight biology and eight physics news titles; for each scientist gender, the four lowest- and four highest-scoring faces on the interest dimension from Study 1 were selected. Study 4 used the four biology titles with the least-extreme interest. Faces were counterbalanced across articles, with one face per attractiveness–competence combination presented per trial. Study 5 and Study 6: four biology and four physics news stories; faces with the two lowest and two highest good scientist scores per gender from Study 1. Study 6 used four physics titles from Study 3 with the least-extreme quality preratings and faces from Study 4.	Traits related to competence (competence, intelligence), sociability (likability, kindness), morality (trustworthiness, honesty), attractiveness, face's age in years Interest in finding out more about this person's research How likely is it that this person is a good scientist	Study 1 and Study 2: scientists who appear competent, moral, and attractive were more likely to garner interest; competent and moral but unattractive or unsociable scientists created a stronger impression of high-quality research Study 3: participants preferred research paired with interesting-looking scientists across gender, discipline, and format; effects were stronger for videos than text, stronger for biology than physics, and influenced by the scientist's gender; female participants and younger participants were more affected by appearance Study 4: interest judgments were higher for participants with high science engagement and older participants; facial competence and attractiveness increased selection of articles. Study 5: research paired with photos of good scientists was judged higher quality, independent of scientist gender or discipline; physics articles and participants with higher science engagement received higher ratings Study 6: more competent-looking scientists were judged more deserving of prizes, attractiveness had a weak negative effect, and older and female participants rated scientists' work as more prize-worthy

Yeo et al. (2022)	Source credibility	2 (gender: female or male) x 2 (race: Black speaker or White speaker) x 2 (credentials: scientist or comedian) Between-subjects design	Experienced mirth	Perceived effectiveness of the speaker	No main effects for gender, race or credentials on perceived effectiveness of the speaker Interaction between mirth and the experimental manipulation of the speaker's credentials, whether the speakers were labeled as a comedian or scientist, only mattered among respondents who reported levels of mirth lower than 5.06 (7-point scale) Among respondents who reported lower levels of mirth, a scientist, relative to a comedian, was perceived by participants to be a less effective communicator
Bigham et al. (2019)	CRISPR technology Source credibility Persuasion	2 (information: control no additional information or treatment emphasized) x credibility (expertise and trustworthiness) x 2 (source: male or female) Block factorial design	Recipients' gender	Credibility perception source	Gender of the source had a significant influence on perceptions of credibility; the female sources were rated highest in source credibility
Hubner et al. (2024)	Source credibility Gender stereotypes	Instagram posts Gender scientist: male or female (name and picture) Between-subjects design	Gender participant	Liking Competence Trust in scientists	Female scientists were rated as significantly more likable than male scientists Mediation effect, for female scientists increased perceptions of competence and trust in science through liking Participants preferred the opposite gender (contrary to gender affinity effect)

Eaton et al. (2020)	Source credibility Stereotype content model	Candidates CV post doctoral position 2 (department: physics or biology) x 2 (candidate gender: male or female) x 4 (candidate race: White or Latinx or Black or Asian) Fully-crossed between-subjects design Sample professors in physics and biology at eight large U.S. public research universities	Competence Hireability Likeability	Faculty participants rated the male candidates as being significantly more competent than the equally qualified female candidates when averaging across faculty department White and Asian candidates rated as more competent and hireable than Black and Latinx candidates across departments Physics faculty gender bias favoring male candidates for perceived competence and hireability Physics racial bias favoring Asian and White candidates as more hireable compared to Black and Latinx candidates Biology department racial bias in hireability, favoring the Asian candidates as more hireable than equally qualified Black candidates

Yuan et al. (2019)	Genetically modified organisms (GMOs) Source credibility Expectancy violation theory	3 (communication style: aggressive or neutral or polite) × 2 (source: expert: scientist or nonexpert: non-scientist) Between-subject factorial design	Expectancy violation	Message quality Writer likability Attitude Behavioral intentions	Source expertise had a stronger positive effect on message quality evaluation when the communicator used an aggressive communication style than when the communicator used a polite communication style Effects of source expertise on writer likability and preexisting attitude toward GMOs on writer likability were stronger when the communication style in use was aggressive Communication style significantly moderated the relationship between source expertise and expectancy violation: when the communicator used a polite communication style, source expertise had a stronger positive relationship to expectancy violation than when the communicator used an aggressive communication style Message quality positively affected purchase intention Writer likability resulted in a negative effect on purchase intention Source expertise had negative indirect effects on perceived message quality and writer likability Preexisting attitude toward GMOs had significant positive effects on message quality and on writer likability

Li et al. (2018)	Nuclear fuel cycle Visual data credibility	2 (graph format: traditional area chart or innovative proportional area chart) x 2 (interactivity: static or dynamic) x 2 (data source: university scientist, Massachusetts Institute of Technology (MIT) or governmental agency, U.S. Department of Energy (DOE)) Between-subjects design	Perceived data credibility Self-assessed design quality	Perceived credibility did not vary when shown different graph formats Respondents were less likely to think the data was credible when viewing a dynamic graph than when viewing a static one (contradicting the initial hypothesis) People who viewed data attributed to MIT perceived higher credibility than those viewing data attributed to DOE Perceived data credibility was positively related to self-assessment of graph quality, which was supported by a significant positive relationship between the two variables
Jarreau (2019)	Online source credibility Visual expert stereotypes	Instagram posts: control (Instagram account of male and female individuals) or science- only male (different scientists) or science-only female (different scientists) or male selfies (different scientists) or female selfies (different scientists)	Enjoyment Perception of scientists Warmth and competence Gender science stereotypes	Participants who had browsed selfies, especially those containing a female scientist's face, perceived the IGers they had encountered to be significantly more trustworthy and warmer than did participants who had browsed control or science-only posts Attractiveness mediated effects of scientist gender on warmth and competence evaluations, selfies from female scientists, evaluated as highly attractive, are perceived as more competent than male scientists The presence of female scientists in IG posts was a significant predictor of female-shifted science stereotypes

König & Jucks (2019)	Scientific claims Source credibility	2 (language style: neutral language or aggressive language) $\times$ 2 (professional affiliation: scientist or lobbyist) Between-subject design	Message credibility Trustworthiness Machiavellianism Likability Expertise, Integrity, Benevolence Attitude Subjective comprehension	Aggressive language led to lower message credibility ratings than neutral language Aggressive language led to lower subjective comprehension ratings than neutral language Aggressive language led to higher machiavellianism ratings than neutral language Being a lobbyist led to higher machiavellianism ratings than being a scientist Aggressive language led to lower expertise ratings than neutral language Aggressive language led to lower integrity ratings than neutral language Being a lobbyist led to lower integrity ratings than being a scientist Aggressive language led to lower benevolence ratings than neutral language Being a lobbyist led to lower benevolence ratings than being a scientist Aggressive language led to lower likability ratings than neutral language Being a lobbyist led to lower likability ratings than being a scientist

Andrews et al. (2025)	GMOs Climate change Source credibility	Study 1: 2 (topic: GMOs or climate change) x 2 (message order: before or after scientist description) x 2 (stance: for or against) Factorial design Study 2: 2 (topic: GMOs or climate change) x 2 (message order: before or after source [YouTube] description) x 2 (stance: for or against) Factorial design	Source expertise Source trustworthiness	Both studies: Expertise and trustworthiness were highest when participants were exposed to a congruent message that echoes their own attitudes on the scientific issue (rather than an incongruent message) Study 1: For expert sources, perceptions of credibility were influenced by participants' pre-existing positions when the description of the source came after the reveal of their position Study 2: Perceived expertise different between incongruent and congruent and ambivalent and congruent conditions
Kim (2015)	Food irradiation Biofuel Online source credibility	3 (others' comments: supporting comments or opposing comments or no comments) × 2 (source credibility: high or low) Between-subject factors Within-subject (issue: food irradiation issue or biofuel) Within-subject factorial design	Perceived others' news acceptance	News evaluation Participants perceived that the majority of the public was more likely to accept the issue position of the news article when they were exposed to a news article accompanied by comments that supported its point of view than when they were exposed to a news article without comments Comment manipulations of supporting or opposing comments had significant indirect effects on news evaluation through perceived others' news acceptance

Haim & Maurus (2021)	Source credibility Gender stereotypes	3 (author: picture male or picture female or picture gender-neutral computer) x 2 (topic: football or movies) x 2 (sexist comments: yes or no) Computer author was only presented with non-sexist comments Between-subject design	Source credibility Message credibility	Computer author was perceived lower in credibility than human authors Covering the counter-stereotypical topic along with non-sexist commentary led to the lowest credibility scores per gender No backlash effect of female journalists who write about a stereotypically masculine topic to be perceived as less credible than male journalists who write about a stereotypically feminine topic Potential reactance effect: availability of sexist comments increased source and message credibility when compared to the same article by the same author when a female journalist counter-stereotypically wrote about a masculine topic female journalist's article was accompanied by sexist comments, both source and message credibility were higher than if a male journalist's article was accompanied by sexist comments Participant's gender did not show any effect on source or message credibility

Sprecker (2002)	Environmental topics: water pollution, rain forest destruction Source credibility Social Judgment Theory (SJT)	2 (funding source: private or public) x 2 (citation style: quote or paraphrase) x 3 (participant involvement, measured as a continuous variable, centered on zero grouped into three levels according to the sixty-sixth and thirty-third percentiles: high or moderate or low) Mixed-subjects factorial design	Source credibility	No main effects for funding source or for citation style Main effect for participant involvement, contrary to expectation: those highly involved rated the scientists as more credible than those less involved

Treise et al. (2003)	Source credibility Uses and Gratifications	2 (domain: .gov or .com) $\times$ 2 source: high-credibility source (NASA) or medium-credibility source (Spacescience) $\times$ 5 (story: astronomy, biology, earth science, physiology, physics) Factorial design	Science Involvement	Motives for using science websites Domain credibility Author credibility Article credibility	Motives related to personal usage, functional usage, using to obtain information about science and verifying facts were positively associated with science involvement Personal motives and verifying facts were positively related to the importance of sponsor credibility. Personal motives, functional motives, and verifying facts were related to the importance of information completeness .gov science sites were rated as higher in both expertise and likeability than are .com sites Science sites were rated higher on expertise than likeability Respondents attributed greater expertise to the article source when it was identified as NASA than when it was identified as a generic site Articles received higher ratings when they were attributed to NASA's website as compared to the generic website High-involvement as compared to low-involvement respondents rated the articles more favorably Author associated with NASA, received higher ratings than when the author was associated with generic site Individuals low as compared to high in involvement considered the source to be more objective Author was seen as more objective when writing for a .gov site than for a .com site

Zhang et al. (2023)	Source identity Parasocial interactions	2 (source identity: scientist or influencer) x 2 (self-disclosure type: professional self- disclosure (PFSD) or personal self-disclosure (PSD)) x 2 (context: environment or health) Between-subjects factorial design	Anti-intellectua- lism	Perceptions of the source as authentic and expert Intentions to engage in PSI Information- seeking intentions Prosocial intentions	Scientists were perceived as higher in authenticity and expertise, elicited higher PSI and information-seeking intentions than influencers PSD perceived as lower in expertise, lower information-seeking intentions than PFSD Health context compared to environment context decreased perceived expertise of the source, elicited lower PSI, and decreased information-seeking intentions Source identity indirectly influenced information-seeking intentions through expertise Source identity and expertise indirectly influenced prosocial intentions through expertise Authenticity indirectly influenced PSI and expertise Self-disclosure type indirectly influenced information-seeking intentions and prosocial intentions through PSI Influencers more effective for eliciting prosocial intentions at all three levels of anti- intellectualism, differences decreased among individuals with higher anti-intellectualism

Isberner et al. (2013)	Biomass as ecological source of energy Health risks electromagnetic radiation cell phones Dual-process-models (ELM and HSM)	2 (presence of graphs: graphs or tables) within- subjects factor x 2 (topic of the texts: biomass or electromagnetic radiation) between-subjects factor	Experience science texts and graphs Working memory capacity	Perceived plausibility of information Situation model strength	Readers with a higher amount of experience perceived the text with graphs as more plausible than the text with tables Readers with a lower amount of experience perceived the graphs as less plausible than the text, possibly due to cognitive load Indirect effect of the amount of experience with texts and graphs on the differences in situation model strength via differences in perceived plausibility
Eom et al. (2025)	Source credibility Gene-editing tool CRISPR-Cas9 Scientist stereotypes	Film clips documentary Human Nature, portraying scientists ("narrator") 2 (gender: female or male) x 2 (race: Black or White) x 2 (actors for each race/gender combination) Factorial design	Moral grandstanding	Scientist credibility (warmth and competence) Attitudes towards Black and White Americans	White scientists were rated higher in warmth and competence than Black scientists Male scientists were rated higher in warmth and competence than female scientist Black female scientists consistently received the lowest ratings across both warmth and competence Scientists who introduced the clip of a White protagonist with albinism (Subject 2) received lower ratings in warmth and competence compared to those who introduced the clip of a Black protagonist with sickle cell anemia (Subject 1)

Good et al. (2010)	Gender stereotypes School teaching Visual presentation	High school chemistry book, counter-stereotypical picture (all female scientists) x stereotypic picture (all male scientists) x mixed gender (both male and female scientists shown equally) Text-based information constant across conditions Sample student's 9th- and 10th-grade	Participant gender State anxiety	Comprehension Career interest	Female students showed higher comprehension in the counter-stereotypic picture condition than in the stereotypic picture condition (n.s. for male students) Students reported a decreased interest in science as an academic subject, but did not alter their interest in pursuing a career in science
Meier (2017)	Source credibility News visualization	2 (author: ministry or Bild.de x 2 (visual: image or info-visual or map		Message credibility	Tabloid newspaper BILD had a negative influence on the perceived credibility of the article, German Federal Environment Agency UBA had a more positive influence Articles with authoring institution BILD with a visualization performed better than the standalone article The map was evaluated more credible than the visualization

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