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Hybrid Imbalance: Collaborative Fabrication of Digital Teaching and Learning Material

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Abstract
Digitization of schools has increased significantly in recent years and is generating a massive innovation boost in education. This development is accompanied by an increased demand for new digital educational objects for schools. The resources required for creating such objects (expert knowledge from teaching contexts versus technological knowledge and infrastructures) are distributed among different groups of actors from digital economy and educational practice. Therefore, the production of such new objects requires new forms of cooperation in the education sector. This article discusses such a hybrid collaboration between a software developer and the teachers of two pilot schools for the creation of interactive learning software. We examine this collaborative relationship in light of different bodies of knowledge that both groups of actors bring to the relationship and that need to be reconciled. We also examine the ways in which the organizational boundaries between schools and companies are temporarily blurred, and the distribution of costs and benefits between the participating groups of actors. By looking at the various dimensions of the cooperative commercial production of these digital objects as well as their (prototypical) experimental stage, the paper analyses the digital transformation of teaching as an innovative social process, structured by economic and educational rationalities.

Keywords Education · Teaching · Digitization · Objects · Knowledge · Ethnography

Introduction

In the course of its history, school teaching has always been exposed to technical innovation. Prominent historical examples of such innovations include the introduction of the chalkboard, use of demonstration experiments in science lessons, or the

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appearance of calculators in mathematics lessons (Lind 1999; Trouche 2003). The digitization of schools sets in motion a powerful innovation process and pressure to innovate. The number of products produced, offered, and advertised by companies in the education industry has risen steeply in recent years: whiteboards and document cameras, online dictionaries, learning videos, interactive textbooks, blackboards and wall maps, learning apps, serious games, video-conferencing platforms, and learning management systems are increasingly being used in the classroom or have already become a constitutive part of teaching.

Like other innovations in educational media in schools, the inclusion of digital technologies is a transformative process with meaningful consequences. In fact, qualitative research on digital educational media and digital technologies in schools—as well as research on material objects—has largely focused on the *consequences* of their use in the classroom and the associated effects. Creation and testing of such objects, however, have hardly been investigated so far. The education industry, concerned with the development and creation of teaching objects and materials and functioning as a "supplying industry" of the school sector, thus, by and large remains a black box for sociological research (Lange 2017). The development of such objects and technologies implies a pre-design and prefiguration of classroom instruction and learning, with respective impact and potential transformative power of digital educational objects in particular. This paper thus takes a step back to observe the development and testing of digital educational objects before they are ready for production.

The creation and production of digital technologies for classroom use poses a central problem for players in the teaching materials industry. While actors in the digital economy have access to resources such as technical equipment, infrastructures, and know-how (e.g., programming), they typically lack content-related expertise and are, therefore, dependent on importing specialized knowledge from teaching contexts. This may include the curricula and teaching subjects, pedagogical preparation of content, and the relevance and needs of teaching practice. Conversely, teachers have pedagogical expertise, but usually do not have any access to the knowledge and capacities to create digital educational media. Using the example of an educational software (hereafter referred to as *screen*[1]) for the three-dimensional and interactive presentation of teaching content, and education-related virtual reality (VR) technology, this paper analyzes the case of a collaboration between a software company that manufactures and commercializes new teaching/learning materials, and two pilot schools that get involved in the creation and testing of these products before they are ready for the market.

We describe the creation of this software as a process in which experts from different fields contribute their knowledge toward innovation in the field of educational media. We analyze how teachers and corporate employees are integrated into each

[1] The software is a virtual learning environment that runs on 3D-capable screens. At the core of the software are stereoscopic models of teaching content and the possibility to interact with these models using a Wii controller. Modules for the *screen* are geared towards natural science content such as the structure and function of the inner ear or particles in electromagnetic fields.

other's practical contexts and how, and to what extent, their technical and pedagogical knowledge transcends the boundaries between schools and software companies. Beyond the context of software creation, we will look at test-runnings of the software and other new technologies in the classroom as a further element of the collaborative relationship. The paper thus provides an insight into both the life cycle of the educational object that exists in various aggregate states (e.g., as a concept, storyboard, or prototype), making it a liminal object, and the actors with their ideas, experiences, and expectations who, in shuttling back and forth between the respective organizations, contribute to the objects' creation.[2]

We discuss this collaboration as a hybrid collaboration—as we understand the term: a shared activity of problem solving (Roschelle and Teasley 1995, 70) that coordinates actors from two divergent knowledge contexts (analog and digital)—and pursue three questions: how does hybrid collaboration work in the production of digital educational media? What resources and knowledge bases are mobilized and mutually made available to both groups of actors? What are the benefits the two groups of actors achieve for themselves from the collaboration? As it will become clear, the innovation process is less about an exchange of knowledge, and more about a one-way supply and inclusion of knowledge into the innovation process. As central characteristics of this collaborative production process, we are going to examine: (1) provision of expert knowledge for provision of technology, (2) varying degrees of granting/gaining access to each other's practical contexts, and (3) unequal distribution of costs and benefits.

Answering the above questions should allow us to contribute to the existing literature in three ways. First, we will enrich qualitative sociological research on materiality and educational objects in schools by broadening the perspective to contexts of their production and testing. This not only allows us to focus on the negotiation processes reflected in the formatting of such objects, but also to trace how new objects move into the context of their application and find their way from programmers' screens to the classroom. Second, we will contribute to research into the digital transformation of school education (using the example of secondary-school education in Germany) by illuminating the dynamics and mechanisms of local collaboration and innovation. Third, we will complement research on boundary-crossing cooperation with a case study of the education sector and its digitization. By analyzing the strategic action of actors in the education industry, we will, overall, contribute to economic sociology, which has neglected the education industry so far.

The article is structured as follows. First, in the review section we locate our contribution in the context of research on materiality and digitization in schools and in the context of research on boundary-crossing cooperation. After a description of our methodology and discussion of the particularities of the education industry and its market, we will turn to the analysis of our case. In the first part of the analysis, we will show how teachers bring their professional, didactic, and pedagogical knowledge into the manufacturing process. It will become clear that this relationship is

[2] Star and Griesemer (1989) propose the term "boundary object" for this social boundary-crossing phenomenon, relating the term to material objects.

less about an exchange than about a one-sided provision of expert knowledge by the teachers, who, vice versa, are not involved in programmers' knowledge or the program codes. Rather, their benefit primarily lies in obtaining tailor-made teaching materials. In the second part, we will expand the focus from manufacturing to testing these tools and other technologies in the school context, thereby shedding light on another facet of the collaborative relationship. We will analyze how developers (company staff) are deployed in schools to get new didactic technologies up and running, and organize the marketing of the product as a commodity. Overall, we will demonstrate how both groups of actors contribute their respective knowledge and interests to the process, but how they also benefit differently from this.

Theoretical Background

The increasing presence of electronic devices and tools requires a more or less fundamental restructuring of the material-technical infrastructure of school teaching and implies significant "transformations in the educational landscape" (Colombo 2016). Research on digitization of teaching has investigated the effects of the inclusion of digital technologies in many ways. Among other things, it has outlined how the coexistence of physical and digital elements produces new distributed activities and forms of interaction (Thibaut et al. 2015), how analog and digital representations of learning content are related to each other (Wiesemann and Lange 2019), how students are brought into new relationships through virtual environments in the classroom (Burnett 2016), and how educational software transforms dyadic teacher-student interaction into a three-way interaction (Birmingham et al. 2002). Other studies show how mobile information technologies and increasing networking challenge traditional roles and hierarchies of school teaching and the epistemic authority of the teacher as well as the authorized canon of knowledge of the school (e.g., Selwyn 2003), transcend boundaries between formal and informal learning (Greenhow and Lewin 2016), and create new identities of teachers and students (Loveless and Williamson 2013).[3]

With their interest in the digital transformation of school education, qualitative studies on digital technologies in schools usually focus on classroom interaction, placing themselves in the tradition of ethnographic school research on the role of teaching and learning materials in general. There are studies that observe teachers and students in situ as to how they introduce and frame educational (as well as everyday) objects and how they use them to illustrate and to make school subjects (e.g., natural sciences, mathematics, and history) accessible for systematization and generalization. These studies focus on the introduction and framing of educational objects, on the co-constitution of instruction through educational objects, the prescriptions that structure their use, and their performative effects (Fenwick

[3] Other approaches to the study of digitization in school are based on an educational policy perspective (Selwyn 2013), a media didactic perspective (Mulders et al. 2020) and the perspective of applied research (Rikala et al. 2013; Wilson et al. 2017).

and Edwards 2010; Fetzer and Tiedemann 2018; Greiffenhagen 2014; Kontopodis 2009; Lawn and Grosvenor 2005; Nohl 2011; Roehl 2012; Sørensen 2011). For this research, school lessons are the central place where the use, impact, and significance of educational objects can be researched and reconstructed.[4]

Since such studies focus on the social use of didactical objects in class, they address objects which have already been designed and fabricated. In other words, their research begins when such goods have already been developed and tested, advertised at trade fairs and in catalogues, financed by cultural administrations, bought, inventoried and sorted by schools, or purchased by students or their families. Questions regarding the development and design, fabrication and testing, distribution, and acquisition of these goods, however, are raised far less frequently. What would be discovered if research were to move one step back in time to observe the creation of schools and lessons in preparation? The line of research that has embarked on this theoretical trajectory (Blaesi 2018; Lange 2017; Pinto 2007) assumes that school instruction does not exclusively take place in the classroom but is also prepared or pre-structured in other locations, at other times, by other actors, and with other means and goals. In other words, school instruction is prepared in advance in different, specific manners in each of these different locations.

On a conceptual level, this reasoning entails an understanding of the school as an organization embedded in a diverse environment that includes ministries of education, publishers, architecture, teaching/learning materials industry etc.[5] These organizations are deeply involved in framing the school as a socio-material event through their actions, guidelines, products, and deliberations. On a methodological level, this assumption calls for seeking out these contexts in order to understand the ways in which considerations, assumptions, or standardizations are inscribed into teaching/learning materials, interior architectures, or organization of exams. However, research on educational objects must not restrict itself to observing classroom instructions, but also needs to look at the fabrication of teaching/learning materials outside the school setting. Based on this idea, the article expands the perspective to the production and testing of new educational objects as a *hybrid collaboration* between teachers and actors of the digital education economy.

Terms such as "heterogeneous cooperation" (Meister 2021), "cross-domain collaboration" (Pershina et al. 2019), "cross-section collaboration" (Di Domenico et al. 2009), or "distributed collaboration" (Fayard and Metiu 2014) refer to a constellation frequently associated with innovations: namely the cooperation of actors from various domains who contribute their specific knowledge and interests to an innovation process and who must coordinate with each other. Such boundary-crossing cooperation is central to the development of new products due to the need to integrate different types of knowledge (Leonard-Barton 1995). This is particularly true

[4] These studies refer to the theoretical considerations on the relation of culture and materiality (e.g., Daston 2004; Kraemer 2015; Latour 1996) and on the understanding that (everyday) theories of teaching and learning, images of teachers and students, their respective ways of using things, and even didactic theories of doing lessons are implemented in these teaching and learning materials.

[5] For an overview on the situatedness of educational software development between politics, administration, economy, and pedagogy, including the respective actors/organizations, see Lynch (2015).

regarding digitization, which, on the one hand, enables new and more unbounded forms of cooperation—for example, via digital platforms (Nambisan et al. 2017), but, on the other hand, creates new “knowledge boundaries” (Dougherty and Dunne 2011), for example, by enhancing the knowledge of programmers and software designers (Pershina et al. 2019).

Research has dealt with such forms of cooperation and collaboration in many ways and with different emphases. For example, studies distinguish between different boundaries and ways of overcoming them (Carlile 2004), identify difficulties and obstacles (Gray 1989; London 1995), and examine the mediatizing role of objects as liminal objects (Carlile 2002), as epistemic objects (Ewenstein and Whyte 2009), or as boundary-crossing tools (Pershina et al. 2019). Dougherty’s (1992) notion of “thought worlds” has become a common concept for the differentiation between the members of different domains of activity and their respective understandings of that activity. We locate our study in this strand of research on cross-boundary work, and analyze the production of digital educational objects in the school context.

We use the term *hybrid* collaboration to emphasize the interaction of actors with digital, technological expertise, on the one hand (programmers: field of economy), and with analog, context-specific (i.e., teaching) expertise on the other hand (teachers: field of education). To emphasize the aspect of joint problem-solving over the aspect of division of labor, we prefer the concept of *collaboration* to the concept of cooperation (Roschelle and Teasley 1995). One main characteristic of this collective work of teachers and programmers is the temporary switch between these forms of working together. In other words, the performance of the collaboration dialectically entails the un-doing of cooperation at the same time, and vice versa. This is more appropriate to our case because this relationship between teachers and programmers is less about division of labor and more about a rather one-sided provision of knowledge. As we will show in the paper, this hybrid collaboration tends to be asymmetric or imbalanced in character. While teachers open up their educational and teaching expertise by presenting it in oral and written forms to the company staff, the programmers conceal the digital code and de-thematize their knowledge of digital programming by presenting a rather closed object (first prototypes) to the teachers. While teachers open the context of the school to corporate employees and allow them to use it for product testing, market observation and even advertising, they are denied access to the backstage of the company.

Methods

The empirical data was collected in a three-year ethnographic research project on the fabrication and use of educational objects (2015–2017). In preparation, we looked for manufacturers of innovative digital educational media, conducted internet research, and visited educational fairs. We finally identified a software manufacturer specializing in the production of interactive models and stereoscopic simulations for school lessons, in particular in the natural sciences. Contact was established through a visit to an education fair where the company was represented. The first project phase focused on observing software development (planning and evaluation discussions, meetings with teachers, programming on screen) and the company's marketing activities (networking activities, presentation of the technology at education fairs, congresses, open days). We participated in planning and evaluation meetings, internal meetings, and development meetings with teachers, observed the programming of models on the screen, accompanied the company representatives at education fairs and congresses, and observed their presentations on products. Learning about their collaboration with local schools and teachers, we soon realized the importance of including teachers and schools in our study, and started talking to teachers from the pilot schools involved in module development and testing. In this way, we were able to reconstruct the genesis of the collaborative relationship, gained insights into the planning and production processes in the generation of new modules, learned about the different perspectives of the actors, and understood how this form of collaboration works.

In the second project phase, we shifted our research focus away from the company and towards the two pilot schools. We initially focused on the inclusion of the jointly developed modules in the lessons, which was observed in science lessons in grades 8 and 9. We observed the use of the software in a number of subjects (chemistry, physics, and biology) and forms of teaching (front-of-class teaching, station learning, individual and group work). Furthermore, we observed the instruction of trainee teachers in the handling of the software and the operation of the associated hardware, and we watched the school use this technology to recruit new students on open days. In addition to the application of the software modules, we observed experimental applications of other technologies such as VR glasses provided to the school within the scope of its collaborative relationship with the software company.

We performed our ethnographic research primarily as participant observation. Where possible, we documented our observations with photos (screenshots, lessons, workplaces, blackboard letters, media practice by teachers, students' work with technology, and instruction by staff). Two lessons were recorded when we were allowed to use audiovisual recording devices. Furthermore, we conducted guided interviews with the management of the company, company personnel, teachers, and students, focusing on the creation, course, and functional nature of the relationship, the exchange and communication processes in the course of the development and testing of the software, as well as its significance for the different actors. This further developed our insights into the contexts of production and use. In addition, we collected documents in the field, such as advertising material of the company, handouts for module creation, press releases and newspaper articles, module views and storyboards, worksheets, and evaluation sheets for assessment of the use of the software and VR glasses (Prior 2003).

Our data included about 120 hours of observation records, eight transcripts of expert interviews with a duration of 40–60 minutes each, three hours of audio-visual recording, and a variety of photos and collected documents. Individual excerpts from audio-visual materials were used for video elicitation in the guided interviews with teachers. The data were analyzed by open coding of the materials according to grounded theory methodology, by the gradual elaboration of categories and the successive relation of the categories and codes to each other, for which we used qualitative data analysis software. The audio-visual material was transcribed for detailed analysis, and images were analyzed partially using Visual Grounded Theory (Konecki 2011). We started our analysis immediately after the first observation and continued it while using any insights gained in analysis for further data generation by way of a circular research process (Emerson et al. 1995). This gave us increasing closure in terms of our analytical focus.

The Education Industry and Its Market

Before we turn to our analysis of this cooperative collaboration between a software manufacturer and the pilot schools in the south of Germany, we are going to have a look at the background and development of this relationship. Companies in the education sector (i.e., publishing houses and other commercial companies) are facing two challenges: technical feasibility of their products on the one hand, and their implementation in the market on the other. For the education industry, the implementation of a product in the market for educational goods is an uncertain undertaking, as this market is essentially state-driven in countries where the state is the main and powerful governing body of (public) schools (e.g., Germany, France, Austria). Economic laws of neoclassical theory tend to lose their power on this market since local administrations, state ministries, and other state institutions essentially decide the fate of the market and its products. In other words, the market for educational goods is not a neoclassical market where, among other things, demand and supply, collaboration and competition determine economic activities. Rather, it is a market with strong state actors that, though lacking a monopoly, do wield decisive power. State actors not only decide on the comprehensive (non-) purchase of educational goods (e.g., whether schools are to be equipped with interactive whiteboards or other teaching and learning materials), but also stipulate the purchasing decisions of students and their families through their curricular plans (e.g., regarding textbooks). Although uncertainty is a main feature of markets in general with severe consequences for economic actors (see Beckert 1996),[6] uncertainty in the market for educational goods has a different appearance. Due to the lack of reliable knowledge about whether a product will be as successful as assumed, companies must continuously observe state administrations in order to assess the prospects of their products.[7]

[6] Market uncertainty comes from the fact that the information needed for optimal investment decisions is unknown. That is to say that economic actors have to decide carefully about their investments, and thus the company's future, based on market or product information provided. On the difference between uncertainty and risk as well as on the benefits of uncertainty, see Knight (1971).

[7] Economic sociology has not yet addressed this particular market constellation in detail. In general, the market for educational goods is a difficult one because innovations are slow to take hold. This is partly due to scarce public funding and time-consuming administrative decision-making processes (Foray and Raffo 2014). For an economic or financial sociological conceptualization of the "market" focusing on pricing, network structures, and organizational and technical coordination, see, for example, Beckert (2002), Callon (1998), and Swedberg (2003). Concerning the idea that markets are a formatted and material entity, we are following Thévenot (1984).

Considering these conditions, the company we observed pursued three strategies. First, it held a series of marketing events aimed at decision-makers, potential "early adopters" (Rogers 2003), and interested parties in the field of education (including the fields of professional training, further education, volunteer work, etc.), and presented its products at education fairs, where it attracted the interest of other social actors (companies, a foundation etc.). The company made use of a modernization narrative for its marketing, according to which the acquisition and use of the digital medium (an interactive three-dimensional learning software) would modernize the schools both technologically and pedagogically. Thus, the company promised a future where digitized media would enable forms of teaching and learning that the schools with their analog media were unable to provide. Development and distribution of the product was thus accompanied by a discursive practice that claimed three objectives: (1) creating a school equipped with modern technology (critique of analog learning media) that would, in turn, (2) guarantee a stimulating learning environment for students (criticism of school instruction), with (3) a modernized concept of knowledge transfer to meet the challenges of contemporary knowledge societies (increased participation of students). This discursive practice had the goal of convincing school and administrative actors of the function, effectiveness, and innovative power of the company's educational object. Thus, the company tried to exert symbolic power over its potential clients through its marketing discourse and practices, creating a desire and demand for such products (Cochoy 1998).

Second, the company changed its strategy, switching from its initial top-down model to a bottom-up strategy after it had become apparent that the initial venture would fail. The top-down model was designed and developed to convince the cultural bureaucracy of a German federal state of the efficacy of its product that would secure sales for the mass digitization of the nation's schools. Individual local schools willing to serve as pilot schools and to participate in the production of learning software were recruited for the bottom-up strategy. This way, the company not only succeeded in recruiting partners, but also secured access to the technical and teaching expertise that was required for the development of its products.[8]

Third, the company implemented a strategy of validation through science. A psychological assessment, acquired specifically for this purpose, concluded that the software could substantially support students' learning success. An employee of the company reports:

> We implemented our own studies here. … An astonishing thing...is that when using [the learning software] cognitive perceptual behavior is activated and sustained to an extraordinary degree. It is assumed that the combination, i.e., of spatial seeing and doing something oneself, contributes causally to the fact that...the subject matter can be better memorized.

[8] Regarding the field of the education industry, we assume that economic actors (the companies) involved in this field are confronted with special economic, commercial and market constellations, which, in turn, have a significant effect on schools and policies (Williamson 2016). Thus, the creation of educational objects cannot be understood separately from these general conditions.

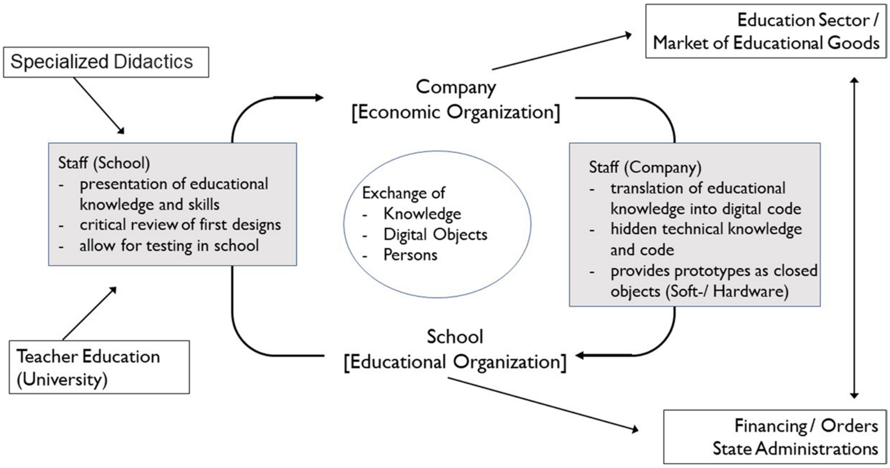

Fig. 1 Circulation of knowledge and objects

Accordingly, the company successfully mobilized another actor to dispel any doubts about the pedagogical-didactic adequacy of the product from a scientific point of view.[9] Symbolic capital (Bourdieu 1977) was transferred to the educational object with an expert's assessment, thereby making it a certified entity. In practice, this happened within the scope of a scientific act of ascription, which attributed specific properties to the object.

Until here, it had become apparent that the company was following what can be described as a trans-organizational model of an extended organization without completely relinquishing control over the product development. However, the company's boundaries did not end at its "factory gates." As we are going to show in more detail below, they rather were extended to other areas—in particular to the pilot schools. The company thus responded to the challenge of the technical feasibility of the product combining a user-centered (Shove et al. 2007) and a participatory design (Spinuzzi 2005). The company worked with an imagined community of users and their social use of the software in this user-centered approach; and its participatory design included teachers (and, in part, students) in the development process.[10]

Thus, a team of programmers and teachers was formed and charged with the task of creating a learning software that would be technically and pedagogically innovative, provide immersive spaces, and be functionally stable. After being forced to make some initial strategic adjustments, the company succeeded in establishing a network of heterogeneous actors in which the development and testing of the learning software was embedded. As a core component of the resulting cooperation, a

[9] In marketing situations, the very presence of the observing sociologists was also sometimes (re)interpreted as physical evidence of the scientific nature of this educational software.

[10] The relevance of object design for educational processes primarily is in communication of such objects (Lawn and Grosvenor 2005) as well as in recognizing, transforming, and, if necessary, reconceptualizing methods of use (Wiesemann and Lange 2019).

practice of mediation between technology (code) and pedagogy (subject matter) in the rooms of the company emerged; as a return service, corporate employees accompanied the demonstrations of new technologies (in particular, VR glasses) at the school (see the analysis below). This mutual process is illustrated in Fig. 1.

The participants were thus involved in each other's practical contexts in development and testing of the digital object. School actors (teachers and students) participated in company procedures on the one hand, while corporate employees (in particular computer scientists) participated in teaching practice on the other. In the following sections, we will analyze this hybrid collaboration in more detail. We focus on the different knowledge bases that the two groups of actors bring into the process and that have to be mediated; the levelling of organizational boundaries for the other actors; and the distribution of costs and revenues between the parties involved.

Teaching Staff in the Company

Development of the learning software was, among other things, the result of a local proximity of the actors and their organizations. Collaboration between the software company and two schools, designated as pilot schools, was thus conditioned by local networks. Interested members of the teaching staff, as well as a few students, advised the company on the development of the digital educational object through regularly scheduled meetings in the company's premises. Based on their expertise and teaching experience, they suggested some new contents and discussed possibilities and limits regarding the realization of their ideas with the programmers. These *teachers-as-developers*[11] also ensured that the school's experiences with the software's capabilities, usability, and reliability were passed on directly to the programmers to help initiate revisions to the software. The company thus recruited local teachers to share their pedagogical expertise and experimental knowledge. One of the participating teachers recounted his collaboration with the company[12]:

> The company was headquartered here and Mr. S. [company's CEO] also comes from here. We were one of the first schools that set out to find partners and to forge collaborations, but not just like, "Hey, do you want to sponsor us?", but based on fixed contracts. ... We were very innovative and open-minded at that time, we had a foundation backing us, and the board of directors then mediated and searched and found. ... And then it just started, and we thought about what to program and what could be done. It was important for us to create something where 3D [three-dimensional] provides *added value* since a software module like this is expensive. Therefore, we considered which subjects would

[11] This is—like our later description of *Developers-as-Teachers*—of course a simplification that focuses on mutual empathy and the assumption of roles. Differences in terms of qualifications, expertise and interests are considered.

[12] Transcription marks: D: developer; I: interviewer; (…): unintelligible. The interviews were conducted in German, the quoted passages were translated by the authors.

> profit from visualization. And then we defined what it should be able to do with the help of the internet and textbooks before they tried to put together a storyboard that we then read again. Then they tried to program that, we looked it over, reported back; it was like a game of ping-pong. … We are really on the wrong track when we say: "You can do this and you can do that, so yeah, let's just do it", since the programmers would say: "Well, we can't do that, we don't have any data, we haven't got a clue how to do it", and that's just how things have worked out.

This teacher summarized how the partnership between the software company and the school came about, how it was shaped, and how the school became a project in itself and for the company. According to this, the school (and its supporting foundation) was actively looking for partners and eventually succeeded in establishing contact with the local company and in codifying the ensuing collaboration.[13] This collaboration was based on the joint creation of learning modules with teachers playing an essential role to that end. They determined the purposes for which stereoscopic visualization would be desirable and suitable from the very outset, spurring the development of new modules. However, they also became involved in the later stages of the developmental process, formulating requirements and criteria for a specific module, and evaluating the drafts of subsequent screen layouts created by developers, all of which constituted important intermediate steps towards realization of the respective modules. One remarkable point is the negotiation process regarding teachers' ideas and their pragmatic adaptation to what is technically feasible by the developers. In other words, expert knowledge of any given subject and ideas for its didactic realization provide a *vision*, while technical expertise is concerned with *re*vision in accordance with the technical and financial resources of the company. This emphasizes the realistic nature of technical knowledge, defining the limits of what is achievable. There is a framework for the creation and design of the object that—at certain stages—sets clearly demarcated, non-negotiable boundaries. In this way, differences between the respective bodies and contexts of knowledge are marked and brought to mind. One of the programmers describes the development process from his point of view:

> D: …teachers know exactly what they must get done in their lessons, they know their subjects. So, they choose what should be represented three-dimensionally, what would have, like, additional value, ... so they look and ask, "Okay, what topics make sense on the *screen*?". And then you sit down together. ... Of course, we then have to think about, okay, how can we realize this technically, how does it make sense? ... They come up with something, right, and then you sit there again and think, ah, okay, well [laughs]. ... And then you have to consider whether that makes sense or whether it doesn't, whether that would blow the budget to hell or not, right? If it doesn't work

[13] For both schools, such partnerships with (mostly locally based) actors from the business sector are rather the rule than the exception. Cooperation agreements like this exist as well with other companies.

out from our point of view, we explain that. ... And then they come back to the next meeting with another storyboard. ...
I: So, you don't start programming up to this point?
D: Not yet, no, no. We will start only after the storyboard is completed. Usually, three of us work on it, whereby the two colleagues take care of the modelling. So, as a rule, teachers provide the content in some way and say, "Okay, this fits the topic here", like copies out of textbooks or something like that. ... I then kinda put it together, as it were, and say, "Okay, we're still missing this, we're still missing that". ... And eventually we have a prototype. ... After we have implemented the content of the storyboard as we understood it, as it is set out there, we show it to the teachers again. They go through it again, find errors, and we fix them, of course.

According to the developer, everything began with the selection of three-dimensional teaching materials that were useful for representation in a three-dimensional format. The selection, made by teachers based on the knowledge of their subjects and their teaching experiences, could be clashing with the developers' technical and economical orientation during the advisory meetings. Both alignments suggest mutually exclusive perspectives, indicating potential disagreement about the module to be developed. The module thereby became an object of knowledge that raised questions as to what should be presented (technical content), how it should be presented (technical implementation of the content), and how it might be accomplished economically (costs, yield). Although the educational-economic goal of the collaboration brought the participants together around the object of knowledge, they emphasized different aspects, different goals, and aligned themselves with different forms of knowledge, while working toward a common goal. In other words, the teachers' subject-didactic visions came up against the technical-economic knowledge of the developers, where the latter's function was to ensure feasibility within the framework of the technical, human, and economic resources that were locally available.

The extract above also indicates that mutual understanding could not be achieved without a mediating entity, specifically the storyboard. Such storyboards served as the first drafts of what was to be seen on the screens from a technical standpoint. For this purpose, teachers made use of teaching materials that they made available to the developers. For information technology (IT) specialists, the storyboard broke down didactic content into "learning objectives," "displays," "interactions," "instructions," and "tasks/solutions," thereby answering questions on the actual content and its presentation, user activity, the subject matter to be taught, and possible exercises and solutions. Using such lists, teachers broke down complex subject matter into clearly separated units and steps. The storyboards were then modified repeatedly in a circular process, until a prototype could finally be created. In this context, a developer reflected on his role:

I: Do you have to actually become a bit of a teacher when developing the modules? Do you imagine yourselves in a teaching role?
D: Yes, we have to. Yeah, sometimes we have to. In order to understand what they want from us. So, in order to understand what the module is supposed to

accomplish in the end, you have to be a bit of a teacher, I think. So, yeah, you have to change your perspective sometimes.

Changing perspective here means trying to understand how the module can be used in the classroom. It also means having at least a partial understanding of the subject matter and of what the students are supposed to take with them from the illustrations provided by the module. The storyboard does not contain any detailed rules for this, but rather relies on the developers' active participation in the process and ability to perceive what is needed.

Then the learning module is put together with the help of programming code developed by the company. The change from cooperation between developers and teachers to solitary work on and with the program stands out here. Working on their computers, developers implement the agreed upon storyboard and discuss problems and results with their colleagues or with the Chief Executive Officer. Programming of the learning software is thus a matter of digitally implementing detailed scripts (namely the storyboards) step by step. Social communication with other actors is only occasionally necessary. An important aspect in this process is that the modules are required to offer a range of possibilities for application or manipulation (Mead 1938, 24), meaning that students shall be able to click, see changes and effects, etc.

The finished prototype is then viewed and retested by the teachers; any errors or ambiguities in the subject matter are recorded and corrected. The teachers' evaluations are based not only on criteria such as the accurate presentation of the learning content, but also on the criterion of added value: teachers assess to what extent the three-dimensional and action-prompting presentation of lesson content provides noticeable advantages over conventional two-dimensional representations in books or CD-ROMs. This point is of decisive importance to the teachers, as one of them emphasized in an interview (see above). Indeed, considering the high costs of development and the amount and duration of personal effort invested, the potential success of any module is to be measured in terms of how it could help improve the practice of teaching above and beyond providing a mere expansion of illustrative possibilities. The resulting pattern of development is illustrated below. The two-sided arrows indicate that this is not a linear but rather a recursive process (see Fig. 2):

As the illustration shows and as mentioned before, product development is based primarily on the integration of the expertise provided by *teachers-as-developers*. They bring their expertise, professional knowledge of school curricula, and teaching experiences to the process to develop new modules, provide teaching materials, and evaluate storyboard-drafts and prototypes. The IT-specialists, in return, use their know-how to implement such ideas, translate content into a programming language or code, and model the corresponding learning environments by creating graphics and models, animations, audio effects, and texts. This way, the company organizes an input of school knowledge and can continue to work on the formal side—the implementation in codes. The crucial pedagogic expertise that the company fundamentally depends on is thus brought in by teachers, who act less as co-producers than as a kind of executive consultants. The teachers' subject-specific knowledge enables the company to develop a marketable product whose content and relevance

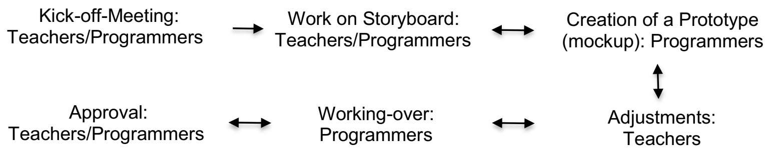

Fig. 2 Stages of the development process

are vouched for by experts, whose future use is certainly probable and which can also be sold to other schools.

All in all, this collaboration is characterized by a certain imbalance: the teachers provide their expertise free of charge and without content restrictions, but the technical aspects of development, decisions about the design process, the use of codes and programming languages, materials, and technical infrastructures remain with the company. While it is true that both parties mutually inform and adjust with each other's perspectives along the way, the impenetrability of computer codes (Edwards 2015) excludes teachers from technical decision-making. The technological knowledge of the programmers, first and foremost represented in the program code, operates as the professional capital of the company and remains withdrawn from further explanation or knowledge exchange in general. Rather, they assume that the object (first prototypes, etc.) sufficiently demonstrates their effort of translating educational knowledge, experience, and expectations into the required digital representations. Both groups of actors thus are involved in a shared trans-epistemic project, but they differ in terms of proximity and distance to the object in question. Instead of *exchanging* knowledge, teachers *provide* knowledge and benefit primarily by receiving digital teaching materials that are precisely tailored to their needs.[14]

The Company's Personnel in the School

After analyzing the involvement of teachers in the company's manufacturing processes, we are now going to look at the other side of the collaborative relationship. The creation of software modules has revealed only on one part of the collaboration relationship, but the relationship extends beyond the boundaries of the company to the school context. This applies to both the testing of the jointly created modules in the practice of teaching and to involvement of further devices and personnel of the company, who, during the collaboration, gain access to school lessons.

The company is present at the school in two ways: first, in terms of the *screen* technology and its inherent assumptions about learning (e.g., how lessons are to be conducted, appropriate behavior of teachers and students, etc.), and second,

[14] The excerpt from the interview with the teacher shows that teachers also benefit personally from crossing organizational boundaries. Their involvement in development and marketing (education fairs, lectures) appears to be a unique opportunity to step out from daily teaching routines and to strengthen their self-understanding of being part of an open and innovative school.

by the attendance of company staff in the classroom. The *screen* and its corresponding learning modules are often used in lessons with a preparatory or remedial character—for example, as a learning station for study groups which conduct experiments in parallel, solve tasks in textbooks, or perform internet research. Students are introduced to the movement of charged particles through a physical experimental set-up, and in the second step, playfully experiment with an interactive *screen* simulation of such particles. Students may also assemble an atom on the screen, the composition of which they studied in their textbook before. In these and other examples, the virtual representation of learning contents complements other modes of representation, making a given phenomenon accessible in a novel way that, in this case, is happening by stereoscopic illustration and interactive handling. The *screen* is thus used primarily for supplementary illustrations: while the teachers refer to the virtual illustrations in later lessons, there are no examination questions on them. In addition to this method, students can upload their own content and use three-dimensional images for their presentations. Beyond this, they can work on the *screen* outside of class and work through or revise lesson content independently.

In particular, those learning modules that are developed with the teachers' help become a significant part of the teachers' school lessons. One module deals with atomic structure, another with the constitution of the human ear, and yet another one with blood circulation. All of them are regularly integrated into the lessons and have a permanent place in the repertoire of teaching media. From time to time, however, teachers or students may encounter mistakes in these modules, as the following excerpt from an observation protocol illustrates:

> The group of four is occupied with the atom-building module when a student in the group calls the teacher over. He had noticed an error in the representation of a carbon atom which evidently does not have the correct number of particles. The teacher looks at the depiction briefly and replies: "If you find something like that, please write it down. We have to report any mistakes that we find."

Such instances indicate that the modules are far from complete prior to their use in the schools. In fact, every encounter with a module in the classroom is regarded as a test run. If the company receives no feedback on it, it is assumed that everything was in working order. In addition to this somewhat coincidental manner of error-detection, there is also a systematic process to detect errors for which students are also recruited. One developer reported:

> D: Well, we also became aware in retrospect that occasionally there were modules that had not been completely thought through, didactically speaking. Either too few people had looked at it or it hadn't been done meticulously enough, so there are still small mistakes, also in the modules that exist so far.
> I: Mhm. Did you find the mistakes by yourselves, without the help of the teaching staff? How did that work?
> D: Or with the help of other teachers, that's interesting. For example, high school X put their groups, their study groups to this task. And they wrote

> pages and pages of protocols for us, saying "there's a mistake, there's a mistake, there's a mistake." So, there's always something, some little thing that you've overlooked, something that the teachers have overlooked. Then you have to go back and take another look.

These procedures allow the company to subject its products to continuous practical testing, thereby obtaining information on the suitability of the modules as well as on any need for corrections and updates. This information is gathered either from on-going lessons or from the workgroup set up specifically for this purpose.[15] Three categories are involved here. First, teachers and students exert themselves as product testers; second, the production process potentially remains incomplete or open ended; and third, the team of developers is extended to include students. The inclusion in this process turns both teachers and students into product testers to some extent. By noticing errors (e.g., formulation errors in the text, content-related issues in the visual presentation, outdated examples that need to be replaced and updated), writing them down in lists and reporting them back to the company from time to time, they initiate revisions to the modules. The software version produced in-house is thus subjected to a further cycle of testing and revision whereby the production of the digital educational object is gradually prolonged over time.[16]

As mentioned before, the company was not only present in the classroom through the learning modules it produced and the hardware it sold, but also through its employees. These *corporate employees-as-teachers* assist in introducing and testing the new software and hardware products in the classroom, provide the necessary technical infrastructure, make things ready for operation, explain the handling of devices, and thus support the application. Usually this happens at irregular intervals and at the request of teachers. During the period that we were able to observe, a VR technology previously not used in the project school was introduced: VR glasses in the form of a head-mounted display with a Wii controller. Both could be tracked from base stations with infrared laser signals. The device's motion-tracking capabilities enabled users to move around in a virtual, three-dimensional space and to examine objects, while the image seen through the VR glasses was also transmitted to an external screen, allowing bystanders to observe the scene along with the user. During our period of observation, the VR glasses were used on two different occasions, the first of which was an astronomy lesson.

[15] The digital educational object can thus be understood as a circulating reference (Latour 1999, 24 et seq.) that goes back and forth between the schools and the company, acting as a vehicle for the exchange of knowledge between the respective organizations. But, as mentioned above, it is important to note that the *screen* technology is available only in a closed format while the software program code is not circulated and instead strictly guarded by the company; only the software versions are shared with the schools.

[16] This interweaving of application and (further) development corresponds to a non-linear concept of innovation characterized by interrelated but not clearly distinguishable phases that has become well-established in social science research on innovation (see Godin 2017). Parallel to product development, innovation also implies the (successful) product placement on the market. The product may be co-designed (Rogers 2003; Hutter et al. 2015).

The unit on astronomy was held over two lesson periods, focusing on planning a mission to Mars. The students were divided into three groups that were assigned different tasks. While the "designers" built a cardboard model rocket, the "scientists" calculated the necessary supplies, and the "pilots" determine the duration of the flight as well as the potential hazards of landing on Mars. During the lesson, the students also engaged with the "Mars Module," a software program developed for the VR glasses that was selected by the teacher for the lesson and pre-installed by the corporate employees. The program enabled a virtual walk-about on the surface of Mars, providing information on, among other things, its constitution, temperature, and geographical features. The program also contained some interactive tasks such as welding work on a damaged Mars rover in the face of a fast-approaching storm (see Fig. 3).

The company assigned two employees to the 'Mars exploration event'. They came to the site half an hour before the lesson commenced, carrying the hardware from the van into the classroom, setting up the base stations, performing the wiring and getting the VR glasses ready for use. While the more experienced staff member supervised the event, the younger one instructed the students on to how to handle the glasses and the controller, and showed them how to move and perform the tasks successfully (such as replacing spare parts on the Mars rover). An excerpt from our field notes provides more detail:

> Two students enter the room. They seem a little reluctant, until the younger staff member calls out to them: "Come on in, we don't bite! Wanna try it out?", holding the VR glasses out to them. The students go up to him. One of them takes the glasses and puts them on under the supervision of the staff member, who then checks that the display is placed correctly. The student, whose field of vision is completely covered by the glasses, looks around in all directions. As the screen shows, he finds himself in a corridor with a door in front of him and a large green button to the right of the door. The staff member places the controller in the student's hand (which is now represented as a glove) and instructs him to reach out for the button and press a button on the controller. The door then opens, revealing a reddish, shimmering sandy landscape behind it. The staff member instructs the student to direct his gaze at a marker on the ground and press the button repeatedly, upon which the scenery changes, and the student suddenly finds himself on the surface of Mars with the landing craft behind him. He begins to walk around, turning his head in all directions and looking at the scenery. A short distance away, he sees a Mars rover with red markings. The employee explains to him that these markings indicate defective parts that need to be repaired. He instructs the student to use the controller to pick up a welding device from the ground, which now becomes visible in his gloved hand. With guidance from the staff member, he attaches the appropriate parts to the Mars rover.

The teacher reported on how this cooperation with the company came about:

> When I saw the film [*The Martian*], I thought that there was so much in it that could actually be used in class. This entire topic, how to create a habitat and so on. Then I saw that there was a Mars software for VR glasses on X [an online portal for computer games]. One has to repair the vehicles currently up there, such as the Mars Explorer or the Mars rover, and one can walk around on the

Fig. 3 Exploring Mars with VR technology

> surface. ... Then I contacted the company and planned the event. That's an area where contact is very worthwhile, to have these technical possibilities.

The company acts as a supplier of new technologies that can be requested by teachers and deployed in the classroom on a trial basis. The cooperation thus not only gives the project school access to the *screen* modules co-developed by its teachers (as well as all other available modules, even if they were developed by other actors such as chemical companies or university students), but also to some new technologies that are not yet part of the teaching process. This allows teachers to implement new teaching ideas relatively spontaneously, experiment with the new technical possibilities and develop new instructional concepts.

As the field notes show, the company not only provides the technology as such, but also the know-how needed for its maintenance and handling. Step by step, the company employee instructed the student on the proper use of the glasses and controller, showed him how to perform manual operations, and gave further advice. As we were able to observe on several occasions, this form of instructions to students in class was no different from the demonstrations given to visitors at trade fairs or congresses. This suggests that the transfer of technology and knowledge to schools is part of the public relations work of the company that allowed it to present its products to a potentially interested public and to establish itself as a point of contact in the field of education.

The company also benefits from such demonstrations that serve as trial runs. Employees make sure that the technology is in working order and give advice to its users, and report their observations back to the headquarters to inform on possible applications, difficulties in every-day practical use, and ideas for modification or for other learning environments. This turns the school into an experimental field for new technologies for both sides. At the same time, this form of technical support also deepens the cooperative relationship between the school and the company.

An additional benefit for the company from such “classroom visits” could be observed at another event when the VR-technology was tried out. A software program originally intended for bio-medical education at the university level was used in a biology lesson. The focus was on an oversize, three-dimensional model of the human heart through which the structure and function of the heart could be examined, blood circulation observed, virtual incisions made, and malfunctions simulated. VR glasses were used as an alternative and as a supplement to the physical dissection of animal hearts taking place in the next room, an activity in which some students were unable or unwilling to participate. Just like in other cases, the company assigned two employees to provide the technology, prepare it for use, and familiarize the students with the controls. The novelty of the technology soon attracted a lot of attention, so that most of the students were eager to use the VR glasses after the physical dissection was completed. One student at a time tried out the glasses, playfully interacting with the model heart while the other students watched what was happening on the screen, gave instructions, and cracked jokes (see Fig. 4).

In this way, the VR technology added an event-like dimension to the biology lesson, which allowed the company to stage the scene for its own purposes. Here is another excerpt from our fieldnotes:

> Suddenly the teacher comes through the door with a mobile table. He is accompanied by several students wearing rubber gloves. On the table there is a bowl containing a blood-covered animal heart and dissecting tools like those used for the dissection in the next room. The teacher places the table a few meters in front of the screen and the student currently trying out the VR glasses. The students are told to gather around the table and the teacher starts the dissection by taking the heart out of the tray and explaining the setup to the students. Meanwhile, one of the employees grabs a camera and starts taking pictures, not only capturing the dissection but also making sure to include the user with the VR glasses and the surrounding students in the picture. The students gather around the table in such a way that no one has their back to the camera.

A deliberate staging of the event for the purpose of producing efficacious advertising photos can be observed here. Since the dissection of animal hearts and the use of the VR glasses took place in two different classrooms, but the photo had to capture both at the same time, the dissection was temporarily relocated to the room where the VR demonstrations took place. The placement of the table, arrangement of the people around it, and the teacher’s actions were all adjusted to the intended theme of the picture, showing the teacher holding the bloody heart in his hand, explaining its structure, and demonstrating the proper placement of the scalpel to interested students, while a student in the background was wearing VR glasses, moving a controller, and experimenting with a model of the heart that was seen on the external screen. The company thus deliberately produced documentations which could be used for public relations work and advertising.[17]

Two things become clear from broadening the view to the testing of the learning software and the experimental use of new technologies. First, the production

[17] The matter-of-factness with which the teacher and corporate employees cooperated in this arrangement confused the ethnographer while students seemed to remain unimpressed.

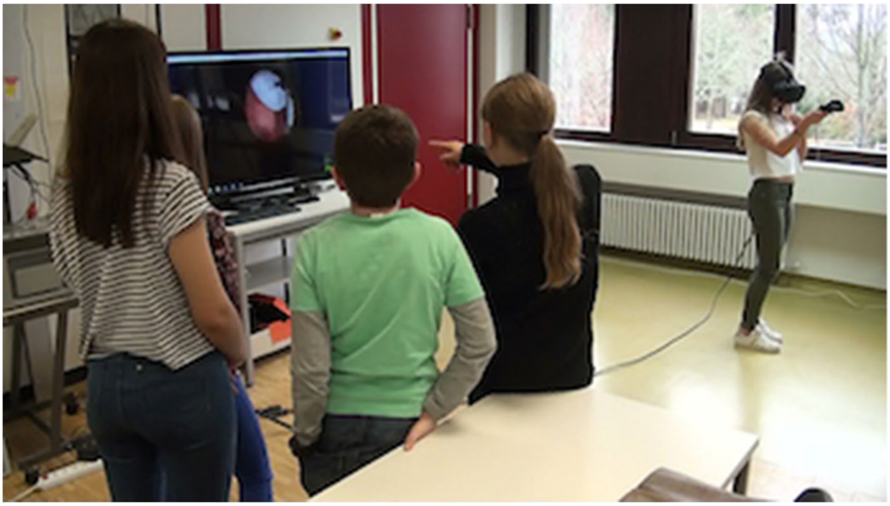

Fig. 4 Exploration of the heart with VR technology

process is not complete with the mere programming of the modules. Instead, the modules are subjected to practical test runs, which may lead to further revision loops. The design and future of the object, therefore, is not closed for the corporate employees. It remains open, as the circle of participants is extended from a few teachers to many students. Second, by giving teachers access to the latest technologies and by assigning corporate employees to arranging, accompanying, and supervising the use of such technologies, the company also gains access to pedagogical contexts, which can be monitored for uses and future needs, and even used in advertising. Even if teachers benefit from the access to new technologies that is granted by the company staff, insofar as they gain the opportunity to experiment with new technologies and try out new teaching formats, there is an imbalance regarding the blurring of organizational boundaries, as the practical contexts of the company remain closed to teachers.

Conclusion

In this paper, we have examined the collaborative relationship between a company in the education industry and the teachers from two pilot schools using the example of the development and testing of an interactive learning software. We analyzed this collaboration regarding the different bodies of knowledge that both groups of actors brought to the relationship and that needed to be reconciled with each other; the ways in which the organizational boundaries between school and company were temporarily blurred; and the distribution of costs and benefits between the participating groups of actors. Regarding knowledge, it became clear that the technical, didactic, and pedagogical knowledge of the teachers, their suggestions, and their visions, were opposed to the technical knowledge of the programmers who would subject those ideas to a critical review for technical feasibility. The storyboard acted as a mediating boundary-crossing object, cycling back and forth repeatedly as it was evaluated and revised several times until it could finally serve as a draft for a feasible module version and as a basis for programming a prototype. In terms of transfer of knowledge, we showed that the collaborative relationship was less about an exchange of knowledge and more about unilateral sharing of knowledge. The software company organized the inclusion of knowledge essential to creating new modules by involving *teachers-as-developers* in the process and using them as knowledge suppliers. However, this input of knowledge was not offset by any technical knowledge provided in return. The program code, for example, would remain within the company and was systematically withdrawn from any knowledge exchange.

Regarding the lowering of organizational boundaries, another imbalance was found in the examined collaboration relationship. While it is true that our case study shows a twofold extension of the respective organizations—the company (education industry) is an actor made present in the school and the school (educational organization) is an actor made present in the company—transparency and access to each other's practical contexts were distributed unevenly. The teachers regularly were guests on the premises of the software company and participated in planning and development discussions there. However, they remained excluded from the technical implementation of the jointly developed ideas, i.e., the programming of the modules. The company's employees, on the other hand, were given access to school lessons and were able to accompany and observe the testing of new technologies there. So, while the school opened its doors to corporate employees, the work of the programmers remained closed to the teachers.

Finally, there were some imbalances in terms of the relationship between costs and benefits on both sides. The programmers profited from being able to use, assess, and incorporate the knowledge disseminated by teachers in the development and design of the learning software. They received ideas for new modules, were provided with teaching materials for the development of the modules and received a technical-critical assessment of their drafts and designs. That way, they could develop the software with guaranteed usefulness in teaching practice and accuracy, and prospects for commercial success. By drawing on the teachers' teaching expertise and professional experiences, the company tried to ensure that there would be a market for its products. In addition, the modules could be improved continually as teachers and students acted as product testers, drawing up records and reporting errors. Beyond this, deploying its employees to technically assist the teachers, the company not only presented itself appropriately to an interested public, but also gained a market observation that could improve already-existing educational objects and develop new ones. The company also benefited from presenting its expertise and its technologies to an exclusive community of users. As shown, the context of teaching was even open for advertising purposes.

The teachers' profits may seem minor when measured against the above benefits for the company. The provision of their specialist knowledge, and the mobilization of their personal time that they invested in participating in the creation of new modules, however, paid off for them as they could create learning software tailored to their practical needs and purposes. Teachers got access to the latest technologies that they could use in the classroom, experiment with, and observe in terms of their suitability for future teaching practices. Thus, they could take advantage of the expanded possibilities of digital media, and achieved an improvement in their teaching practice.

In other words, although the company depended on the teachers' willingness to share their expertise in testing and reviewing initial prototypes, a rather one-sided exchange of knowledge was established, once the cooperation was set in motion and transformed into a collaboration. The process was successful because the company could design and improve the intended product as a collective good and mobilized the appropriate human resources for collaboration in the world of industry (Boltanski and Thévenot 2006). It is also important that the finished product came with a number of merits, such as economic success, pedagogical-didactic relevance, usefulness, and desirability. However, teachers' expertise was not exchanged with the (technical) expertise of the programmers, but with the digital object they would create. This means that, the educational knowledge documented orally and in writing was locally exchanged with the learning software and its symbolic surplus for teaching. These imbalances, along with the corporates' tendency to economize teachers' expertise and to commodify learning contexts in schools, point to a clear imbalance of power in favor of the actors from the digital economy. Our case study, therefore, suggests that processes of school digitization contribute to a one-sided relationship between education, technology, and commerce.

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References

Beckert, Jens. 1996. What is sociological about economic sociology? Uncertainty and the embeddedness of economic action. *Theory and Society* 25: 803–840.

Beckert, Jens. 2002. *Beyond the market. The social foundations of economic efficiency*. Princeton: Princeton University Press.

Birmingham, Peter, Chris Davies, and Christian Greiffenhagen. 2002. Turn to face the bard. Making sense of three-way interactions between teacher, pupils and technology in the classroom. *Education, Communication & Information* 2 (2/3): 139–161.

Blaesi, Christoph. 2018. Educational publishers and educational publishing. In *The Palgrave handbook of textbook studies*, ed. Eckhardt Fuchs and Annekatrin Bock, 73–93. New York: Palgrave Macmillan.

Boltanski, Luc, and Laurent Thévenot. 2006. *On justification: Economies of worth*. Princeton: Princeton University Press.
Bourdieu, Pierre. 1977. *Outline of a theory of practice*. Cambridge: Cambridge University Press.
Burnett, Cathy. 2016. Being together in classrooms at the interface of the physical and virtual: Implications for collaboration in on/off-screen sites. *Learning, Media and Technology* 41 (4): 566–589.
Callon, Michel. 1998. *The laws of the markets*. Oxford: Blackwell.
Carlile, Paul R. 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization Science* 13 (4): 442–455.
Carlile, Paul R. 2004. Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. *Organization Science* 15 (5): 555–568.
Colombo, Maddalena. 2016. Introduction to the special section. The digitalization of educational practices: How much and what kind? *Italian Journal of Sociology of Education* 8 (2): 1–10.
Cochoy, Franck. 1998. Another discipline for the market economy: Marketing as a performative knowledge and know-how for capitalism. *The Sociological Review* 46 (1_suppl): 194–221.
Daston, Lorraine. 2004. *Things that talk. Object lessons from art and science.* New York: Zone Books.
Di Domenico, Maria Laura, Paul Tracey, and Helen Haugh. 2009. The dialectic of social exchange: Theorizing corporate-social enterprise collaboration. *Organization Studies* 30 (8): 887–907.
Dougherty, Deborah. 1992. Interpretive barriers to successful product innovation in large firms. *Organization Science* 3 (2): 179–202.
Dougherty, Deborah, and Danielle D. Dunne. 2011. Digital science and knowledge boundaries in complex innovation. *Organization Science* 23 (5): 1467–1484.
Edwards, Richard. 2015. Software and the hidden curriculum in digital education. *Pedagogy, Culture & Society* 23 (2): 265–279.
Emerson, Robert M., Rachel I. Fretz, and Linda L. Shaw. 1995. *Writing ethnographic fieldnotes*. Chicago: University of Chicago Press.
Ewenstein, Boris, and Jennifer Whyte. 2009. Knowledge practices in design: The role of visual representations as epistemic objects. *Organization Studies* 30 (1): 7–30.
Fayard, Anne-Laure, and Anca Metiu. 2014. The role of writing in distributed collaboration. *Organization Science* 25 (5): 1391–1413.
Fenwick, Tara, and Richard Edwards. 2010. *Actor-network theory in education*. London: Routledge.
Fetzer, Marei, and Kerstin Tiedemann. 2018. The interplay of objects and language in the process of abstracting. In *Language and communication in mathematics education: International perspectives*, eds. Judit N. Moschkovich, David Wagner, Arindam Bose, Jackeline Rodrigues Mendes, and Marcus Schuette, 91–104. Dordrecht: Springer.
Foray, Dominique, and Julio Raffo. 2014. The emergence of an educational tool industry: Opportunities and challenges for innovation in education. *Research Policy* 43 (10): 1707–1715.
Godin, Benoit. 2017. *Models of innovation. History of an idea.* Cambridge, MA: MIT Press.
Gray, Barbara. 1989. *Collaborating: Finding common ground for multiparty problems*. San Francisco: Jossey-Bass.
Greiffenhagen, Christian. 2014. The materiality of mathematics: Presenting mathematics at the blackboard. *The British Journal of Sociology* 65 (3): 502–528.
Greenhow, Christine, and Cathy Lewin. 2016. Social media and education: Reconceptualizing the boundaries of formal and informal learning. *Learning, Media and Technology* 41 (1): 6–30.
Hutter, Michael, Werner Rammert, Hubert Knoblauch, and Arnold Windeler. 2015. Innovation society today. The reflexive creation of novelty. *Historical Social Research* 40 (3): 30–47.
Knight, Frank. 1971. *Risk, uncertainty and profit*. Chicago: University of Chicago Press.
Konecki, Krzysztof Tomasz. 2011. Visual grounded theory: A methodological outline and examples from empirical work. *Revija Za Sociologiju* 41 (2): 131–160.
Kontopodis, Michalis. 2009. Documents' memories. Enacting pasts and futures at the School for Individual Learning-in-Practice. *Memory Studies* 2 (1): 11–26.
Kraemer, Sybille. 2015. *Media, messenger, transmission. An approach to media philosophy*. Amsterdam: Amsterdam University Press.
Lange, Jochen. 2017. *Schulische materialitaet: Empirische studien zur bildungswirtschaft*. Berlin: DeGruyter.
Latour, Bruno. 1996. On interobjectivity. *Mind, Culture, and Activity* 3 (4): 228–245.
Latour, Bruno. 1999. *Pandora's Hope. Essays on the Reality of Science Studies.* Cambridge, MA: Harvard University Press.

Lawn, Martin, and Ian Grosvenor. 2005. *Materialities of schooling. Design, technology, objects, routines.* Oxford: Symposium Books.
Leonard-Barton, Dorothy. 1995. *Well springs of knowledge: Building and sustaining the sources of innovation*. Boston: Harvard Business School.
Lind, Gunter. 1999. Der Physikunterricht an den deutschen Gymnasien vom Beginn des 18. Jahrhunderts bis zum Beginn des 20. Jahrhunderts. In *Das schulfach als handlungsrahmen. vergleichende untersuchung zur geschichte und funktion der schulfächer*, eds. Ivor F. Goodson, Stefan Hopmann, and Kurt Riquarts, 109–150. Köln: Böhlau.
London, Scott. 1995. *Collaboration and community*, 5–6. Richmond: VA, Pew Partnership for Civic Change, University of Richmond.
Loveless, Avril, and Ben Williamson. 2013. *Learning identities in a digital age: Rethinking creativity, education and technology*. London: Routledge.
Lynch, Tom Liam. 2015. *The hidden role of software in educational research*. New York: Routledge.
Mead, George Herbert. 1938. *The philosophy of the act*. Chicago: University of Chicago Press.
Meister, Martin. 2021. Heterogene kooperation, grenzzonen und grenzobjekte. In *Handbuch innovationsforschung*, ed. Birgit Blättel-Mink, Ingo Schulz-Schaeffer, and Arnold Windeler, 493–508. Wiesbaden: Springer VS.
Mulders, Miriam, Josef Buchner, and Michael Kerres. 2020. A framework for the use of immersive virtual reality in learning environments. *International Journal of Emerging Technologies in Learning* 15 (24): 208–224.
Nambisan, Satish, Kalle Lyytinen, Ann Majchrzak, and Michael Song. 2017. Digital innovation management. reinventing innovation management research in a digital world. *MIS Quarterly* 41 (1): 223–238.
Nohl, Arnd-Michael. 2011. *Paedagogik der dinge*. Bad Heilbrunn: Klinkhardt.
Pershina, Raissa, Birthe Soppe, and Taran Mari Thune. 2019. Bridging analog and digital expertise: Cross-domain collaboration and boundary-spanning tools in the creation of digital innovation. *Research Policy* 48 (9): 103819. https://doi.org/10.1016/j.respol.2019.103819.
Pinto, Laura Elizabeth. 2007. Textbook publishing, textbooks, and democracy: A case study. *Journal of Thought* 42 (1): 99–121.
Prior, Lindsay. 2003. *Using documents in social research*. London: Sage.
Rikala, Jenni, Mikko Vesisenaho, and Jarkko Myllaeri. 2013. Actual and potential pedagogical use of tablets in schools. *Human Technology* 9 (2): 113–131.
Rogers, Everett M. 2003. *Diffusion of innovations*. New York: Free Press.
Roehl, Tobias. 2012. From witnessing to recording: Material objects and the epistemic configuration of science classes. *Pedagogy, Culture & Society* 20 (1): 49–70.
Roschelle, Jeremy, and Stephanie D. Teasley. 1995. The construction of shared knowledge in collaborative problem solving. In *Computer supported collaborative learning*, ed. Claire O'Malley. Berlin: Springer.
Selwyn, Neil. 2003. Schooling the mobile generation. The future for schools in the mobile-networked society. *British Journal of Sociology of Education* 24 (2): 131–144.
Selwyn, Neil. 2013. *Education in a digital world: Global perspectives on technology and education*. New York: Routledge.
Shove, Elisabeth, Matthew Watson, Martin Hand, and Jack Ingram. 2007. *The design of everyday life*. New York: Berg.
Sørensen, Estrid. 2011. *The materiality of learning: Technology and knowledge in educational practice*. Cambridge: Cambridge University Press.
Spinuzzi, Clay. 2005. The methodology of participatory design. *Technical Communication* 52 (2): 163–174.
Star, Susan Leigh, and James R. Griesemer. 1989. Institutional ecology, "translations" and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39. *Social Studies of Science* 19 (3): 387–420.
Swedberg, Richard. 2003. *Principles of economic sociology*. Princeton: Princeton University Press.
Thévenot, Laurent. 1984. Rules and implement. *Investment in Forms. Social Science Information* 23 (1): 1–45.
Thibaut, Patricia, Jen Scott Curwood, Lucila Carvalho, and Alyson Simpson. 2015. Moving across physical and online spaces: A case study in a blended primary classroom. *Learning, Media and Technology* 40 (4): 458–479.
Trouche, Luc. 2003. From artifact to instrument: Mathematics teaching mediated by symbolic calculators. *Interacting with Computers* 15 (6): 783–800.
Wiesemann, Jutta, and Jochen Lange. 2019. Manufacturing education. The commercial development of educational products for schools. *British Journal of Sociology of Education* 40(1):114–127.
Williamson, Ben. 2016. Digital education governance. Data visualization, predictive analytics, and real-time policy instruments. *Journal of Education Policy* 2: 123–141.
Wilson, Dawn, Katie Alaniz, and Joshua Sikora. 2017. *Digital media in today's classrooms: The potential for meaningful teaching, learning, and assessment*. Lanham: Rowman & Littlefield.

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