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EMPIRICAL STUDY

Interobjectivity and Interactivity: Material Objects and Discourse in Class

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Abstract In classroom teaching, material objects like the blackboard play an important role. Yet qualitative research on education has largely ignored this material dimension of education and focused on interaction and discourse. Both dimensions are, however, closely related to each other. Material objects are embedded in classroom discourse and are transformed into knowledge objects by speech acts, and in turn structure discussions and constitute a point of reference for school lessons. Drawing on ethnographic research on classroom lessons in mathematics and science classes in German high schools, we propose a perspective that recognizes both the materiality of teaching and its interactive dimension.

Keywords Materiality · School knowledge · Education · Ethnographic research · Performativity

Introduction

Classroom discourse is centred around academic knowledge. The participants talk about mathematical functions, historic events, a foreign language, and so on. In doing so, they usually follow a typical pattern—teachers ask questions, students answer, and teachers in turn comment on the students' answers. Yet, by looking at classroom discourse alone one cannot account for the rich fabric of school lessons and the academic knowledge presented therein. Teachers employ a range of material objects to convey knowledge to their students: blackboards, demonstration experiments in science, geometric models in mathematics, maps in geography,

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and so on. Without them, teaching and learning would certainly be different and sometimes impossible.

In school lessons, these material objects visualise and depict 'subject matter' in quite different ways, and, thus, make it available as a point of reference for discussion. We will study how these objects are used by teachers and students, how they shape what they represent, and how classroom lessons are accomplished by them; the focus is on the role of classroom discourse and material objects in the classroom, their characteristics and social effects. We argue that the relation of social practices and objects in school lessons is balanced out by three dimensions: Firstly, by the social context within which objects are used, manipulated, described and transformed into signs; secondly, by the material setting in which objects are embedded and are part of; thirdly, by the theoretical knowledge inscribed into these objects. In this vein, science and math classes can be understood as a dense context in which discourse and material objects stabilize each other while assigning a relatively fixed status to the objects in use.

The aim of this paper is twofold. On the one hand, it investigates the interplay of classroom discourse and material objects in school lessons. On the other hand, it argues for a position that recognizes both the social construction of objects through interaction and discourse (*interactivity*; see Goffman 1974) *and* the constitution of classroom discourse through material objects and the network they create (*interobjectivity*; see Latour 1996). We see our research situated in a larger theoretical debate on material objects and their role for social lifeworlds (see for instance Cerulo 2009; Pels et al. 2002).

The empirical data we present here is derived from ethnographic fieldwork in German secondary schools (*Gymnasien*) concerned with classroom interaction and the role of objects in education. Following teachers and students through their daily routines, we spent 2–4 months in five *Gymnasien*.[1] The school lessons we observed adhered to a traditional teacher-centred style of instruction (see for more detail Kalthoff 1997). A wide array of data was collected in the field: transcripts of interviews with teachers, field notes, audio and video recordings of school lessons, pictures and sketches of classrooms and material objects. We hope that the material we are going to document and analyse will also give insight into German school culture.

In the following we will selectively sketch the literature on materiality in social theory, philosophy, and education, and give an outline of research on classroom discourse. We will then describe and analyse the social use and effects of two types of objects in mathematics and science classes and how classroom discourse and the use of objects are intertwined, and how they mutually stabilize and affect each other. Finally, we will summarize our findings and discuss consequences of our research.

[1] After elementary school (grades 1–4) students enter the first phase of secondary school (grades 5–9/10) in one of three different types of school (*Hauptschule*, *Realschule*, *Gymnasium*) which are differentiated according to their emphasis on either practical or theoretical knowledge. The second phase of secondary school (grades 11–12/13) takes place in the *Gymnasium* only, leading to a higher education entrance qualification (*Abitur*).

Perspectives on Materiel Objects and Classroom Discourse

Material Objects in Sociology and Beyond

The idea that objects are important for human practice and sociality is a long-standing one (for example in the work of Marx or Durkheim). Bourdieu's work also often hints at the role of objects, for instance in his paper 'Men and Machines' (1981). For Bourdieu the habitat is history which has accumulated within objects throughout the course of time (machines, buildings, monuments, books, theories, etc.). In his study on the Kabyle house (Bourdieu 1979) the role that Bourdieu assigns to objects becomes even clearer. The things that are in this house (such as the weaving loom, the centre pier, the principal beam) all put an order into the space of the house and thus the social world (for example regarding the sexes). The Kabyle house is the epitome of social order which has materialized in the objects which in turn represent the house. Within the materialization, however, the house does not stand merely for a symbolic representation of cognitive dispositions, but rather prefigures the action of the people living in it.

According to Mead (1972; see also Joas 1997: 145–167), using and dealing with physical things requires us to observe the role of these objects and anticipate their behaviour and their resistance. For Mead, physical things resist our attempts of using them and withdraw from our grasp. Similarly, Heidegger (1962) points out that equipment like a hammer can malfunction or break. As soon as that happens it becomes apparent that many features of objects are only available and able to be experienced when in use; they are objects of utility and serve a certain purpose. Postphenomenological accounts of technology draw on Heidegger and Merleau-Ponty to trace the embodied and sensuous qualities of material objects in their relation to human actors. In that vein, Ihde (1990: 72–123) identifies different relations that mediate how the world is present to humans via technological artefacts. Some artefacts become a quasi-transparent part of our bodies, while others are encountered as display of hermeneutic signs. Verbeek (2005) builds on that to show how objects invite some actions and inhibit others via their sensuous qualities.

A particularly prominent contribution to the issue of materiality has certainly been made in Science and Technology Studies. These studies share an emphasis of the embodied and material aspects of scientific and technological knowledge. They reject the idea that science is a linear and solely cognitive process and found, for example, that science involves a great deal of ad-hoc 'tinkering' with tools and objects at hand (Knorr Cetina 1981). Latour and Woolgar (1986) see the scientific laboratory as a place in which laboratory equipment is employed to transform material substances into semiotic representations. Pinch and Bijker (1987) describe the development of technological artefacts as socially constructed. Initially, technological artefacts are open to 'interpretative flexibility,' i.e. different groups of social actors share different meanings about an object. Over time this flexibility diminishes and usually a single interpretation emerges out of this process of 'closure'. In a more radical, post-humanist vein, Latour (1999) proposes a 'symmetric anthropology' in which objects are treated as "actants" in a network comprising of non-human and human actors alike, thus providing a perspective that serves to emphasise the role objects play. According to Latour, material objects demand the performance of very specific actions. These "scripts" are materially embodied in objects. For instance, a blackboard in a classroom requires teachers to competently use chalk in order to write and draw something on it, and at the same time directs the students' attention to its surface. Consequently, a blackboard is not a mere tool used by human actors, but part of a network in which neither human nor non-human actors are favoured. The teacher, the students and the blackboard are all fundamentally altered as part of this network. A hybrid of teacher, class, and blackboard emerges.

The questions posed by social theorists, philosophers and proponents of STS mentioned above are relevant to social theory and sociology in general. There is still disagreement about how to analyse the contribution of material objects to human practice and sociality. The post-humanism of ANT with its emphasis on the agency of objects is, for example, criticised by accounts that demonstrate how material objects are determined by their use and ascription of meaning through human actors (Bijker 2010; Vandenberghe 2002). This article is a contribution to the ongoing debate and tries to take material objects and their constitutive role seriously, while at the same time recognizing the manifold ways in which human actors use these objects.

The Materiality of Education

The sociology of education has rarely dealt with material objects of the classroom. Studies that follow Bourdieu's and Passeron's socio-cultural reproduction model (Bourdieu and Passeron 1990) to explain social inequalities in education see objects as symbols of social class (e.g., De Graaf et al. 2000). The role of objects in conveying knowledge in school lessons is, however, not dealt with. Yet there are some studies on informational computer technology (ICT) and its effects on the classroom by sociologists of education and other educational researchers (e.g., Kritt and Winegar 2007; Smith et al. 2007). These studies deal with the implementation of new technologies and often focus on educational questions. While, for example, Beauchamp and Kennewell (2010) demonstrate that certain forms of ICT encourage dialogue in the classroom, they do not aim to describe how a material object like a computer or an interactive whiteboard are embedded within classroom discourse. The technological artefacts are treated as black boxes that have some effect on education. How this effect comes about, and how the material objects are used, is often left unexplored (see Selwyn 2010). Nonetheless there are studies which deal with the effects of ICT on the school lessons in more general terms, and which try to explain how technologies contribute to education (e.g., Lawson and Comber 2000; Monahan 2005).

Among ethnographic accounts of education, several strands can be identified that deal extensively with various material objects in education. Research on education that draws on Vygotskian socio-cultural activity theory (see Engeström et al. 1999) emphasises the role of symbolic and material artefacts as mediating tools that facilitate learning (e.g., Cobb 2002; Schliemann 2002). In that vein, Brown (2009) investigates how curriculum materials (textbooks, lab tools, etc.) are enacted by teachers in the classroom and how these materials constrain and enable certain actions of teachers. While educational reform often sees curriculum materials as a way of bringing new educational ideas into the classroom, researchers are sceptical about such ideas of linear transmission (Ball and Cohen 1996; Remillard et al. 2009). Teaching is seen as an active enactment of curriculum materials—teachers improvise and adapt the materials according to their experience, their students, institutional constraints, and so on. The focus of this strand of research is on the educational outcomes of employing material objects as 'tools'. However, a question mostly left unanswered is how exactly teachers use and work with these material objects (see Selwyn 2010: 67) and how that use is connected to classroom discourse.

Some ethnographies of education that are more in line with sociological interactionism also deal with material objects. Macbeth (1994), for example, shows how teachers use the blackboard to create a public coherence of a problem that—as an 'essential instructional fiction' (Macbeth 1994: 328–330)—can easily be recognized by pupils. Birmingham et al. (2002) research how learning software changes the 'two-way interaction' of the classroom into a 'three-way interaction' which the computer is a part of. Thus, the teacher's deictic gestures directed at the computer screen become part of the structure of classroom discourse and trigger replies from students. Lynch and Macbeth (1998) demonstrate how a experiment in science lessons is enacted as spectacle by a 'concerted ordering of eyes, ears, hands, entire bodies, equipment, and discursive actions' (Lynch and Macbeth 1998: 277). In a more postmodernist vein, Leander (2002) researches how semiotic and material 'identity artifacts' constitute students as having a racial identity.

Finally, there is an increasing body of ethnographic research on education that heavily draws on STS concepts and thinking (e.g., Fenwick and Edwards 2010; Hall and Stevens 1995; McGregor 2004; Roehl 2012; Roth 1998; Waltz 2006). Some of these studies explicitly focus on the role of material objects in the classroom and how these objects actively contribute to school lessons. Sørensen (2009), for example, heavily draws on ANT to describe spatial assemblages that objects like the blackboard or computers are part of. While the blackboard and its assemblage create a regional space and are better suited to create traditional, representational knowledge, progressive learning software can bring forth 'liquid knowledge' (Sørensen 2009: 125–130). This type of knowledge is processual and constantly evolving. The STS strand opens up the black box of educational objects and systematically questions how objects contribute to and transform education (for mathematics classes see Fetzer 2009). We assume that studies on classroom teaching can profit from methodological and theoretical insights gained in Science and Technology Studies focussing on networks of material objects. At the same time we underline the importance of the discursive and interactive accomplishment of classroom lessons.

Classroom Discourse

There are a number of studies on classroom discourse and its organization. Interactionist accounts of school lessons often focus on the discursive means of establishing the (asymmetric) interaction order of the classroom in which the teacher is endowed with authority (e.g., Hammersley 1976; Vanderstraeten 2001). Similarly, researchers in science education often highlight the linguistic dimension of learning science (e.g., Lemke 1990; for an overview see Kelly 2007). From the perspective of conversation analysis, classroom discourse can be distinguished from everyday conversation in that the permutability of speakers and the equivalence of the social actors are nullified (see McHoul 1978). The teacher has the right to determine official speech time slots for each student. This allocation of turns is closely connected to the structure of classroom discourse. According to Mehan (1979), the typical pattern of classroom discourse consists of an initiation (usually a question) by the teacher, followed by the reply of a student, and finally an evaluation of that reply by the teacher. The decisive element is that the teacher's initial question systematically reserves his/her right to comment on the answer. After students have answered the teacher's question, it is automatically the teacher's turn again. Thus, over time, the constellation question-answer-commentary continually reconstitutes the symbolic regularity of the speakers and the control of the discussion.

Payne and Hustler (1980) show that teachers view their students in a 'synecdochic relationship'. While the teacher seems to be talking to only one student, he is actually talking to a part of the class; when one student speaks, her utterance stands for herself and for the part of the class she represents. Our research (Kalthoff 2004) further demonstrates that teachers intensify this type of relationship by classifying their students according to different types of questions: students capable of repetition, students capable of reorganization and students capable of transferral of knowledge. Although not exclusively, particular students or parts of the class are asked one or the other type of question. Thus, the teacher's comment not only signifies correct knowledge to the class, but also performatively ascribes a status to the student giving the answer. Research on classroom discourse vividly illustrates how talk is linguistically and socially organized in school lessons. But research on classroom discourse has not yet dealt with the material objects in the classroom. Existing transcripts of school lessons focus on situations in class in which teachers and students were engaged in discussions. Situations in which the blackboard or demonstration experiments figured prominently are neglected.

Teaching with Material Objects

While classroom discourse is an important means of producing and representing knowledge in school lessons, it is usually complemented by material objects and semiotic representations (e.g., on the blackboard). Classroom teaching makes extensive use of the sense of sight: Knowledge is made visible, either by a range of objects (e.g., a prism in math classes) or, of course, by writing on paper, on the Blackboard, etc. We will elaborate two cases that have mostly been overlooked by research on educational technology with its focus on innovative technology: knowledge objects (e.g., demonstration experiments), and the blackboard in mathematics and science classes.

Knowledge Objects

Teachers in science and math classes employ a vast array of artefacts to convey knowledge to their students: various devices and objects in demonstration experiments illustrate the laws of science, geometric models demonstrate features of prototypical geometric objects. Sometimes even a mundane artefact like a pen can be used to teach general principles of gravity. With Rheinberger (1997) we understand these objects as knowledge objects because they embody the knowledge that has to be learned. The objects themselves unveil a phenomenon and are at the centre of attention.

As soon as a teacher introduces these objects, almost all of the students focus on the object in question. They stop their informal conversations, bend their bodies towards the object, and direct their gaze at it—students in the last rows often stand up to get a better look. Individually, these objects have a singular appearance in the classroom and they are announced as special objects ('I've brought you something!'). As such they draw a lot of attention to themselves: There is something to be seen, but only for a limited time. As Mr. Frankfurter (one of the teachers we observed) said jokingly to a student who was allowed to leave the classroom during a demonstration: 'You're going to miss the spectacle!' This holds especially true for demonstration experiments. They are one-time events that create a sense of witnessing something first hand. Furthermore, experiments do not only represent something symbolically; they are what they represent, and hence create an immediate presence of the laws of nature. Such a presence is far more powerful than any symbolic representation (Gumbrecht 2004).

Discoursive Transformation of Mundane and Educational Objects

How do teachers employ these material artefacts as knowledge objects capable of drawing attention to themselves? We observed that the status of these objects as knowledge objects cannot be taken for granted and that teachers actively shape them as such. They have to be transformed discoursively in order to represent scientific knowledge. Consider the following example from our ethnographic observation of a mathematics class:[2]

> I entered the classroom of class 10b (15–16 years old) for the first time, closely following Mr. Frankfurter, the mathematics teacher of that class. After some administrative work and mutual greetings, Mr. Frankfurter introduced me and a geometric model of a prism with the following words: 'I've brought you two things: a prism and Mr. Roehl'.

The classroom is a place in which certain 'things'—like a prism and sociologists—require an explanation of their presence. Unlike the blackboard or the teacher's bag, they are uncommon visitors to the classroom and their status is unclear. Moreover, the prism is not a knowledge object simply by being designed and built as such, but must be addressed by the teacher in that way. After the sociologist introduced

[2] The identities of our participants have been disguised using pseudonyms.

himself and his research, Mr. Frankfurter explained the prism in detail. He constantly turned the object in his left hand, pointed at various sides and edges, and addressed the relevant features orally. In doing so he guided the attention of his students not only to relevant features of the object, he also constituted the plastic artefact as a knowledge object for the students.

Teachers thus actively shape artefacts so that they can transfer knowledge. This is mainly achieved via oral language and pointing gestures. Objects in education are not knowledge objects by default, but have to be carefully introduced by teachers as such. They are subject to the 'interpretative flexibility' described by Pinch and Bijker (1987). This holds especially true for everyday artefacts. While some objects were designed and produced for teaching purposes, others were not. This difference has important consequences for teachers using these artefacts. In another lesson, Mr. Frankfurter brought three packs of copy paper along, carrying them under one arm. Suddenly, one of the students asked in despair: 'Are we taking a test?' Mr. Frankfurter replied calmly: 'Do you think we need 1,500 sheets of paper for that? I'm going to show you something with them'. Later, Mr. Frankfurter used the sheets to demonstrate Cavalieri's principle.[3] Similarly, when Mr. Hecker, the young teaching assistant, brought a model of an airplane to the same class, he started by announcing, 'I've brought something with me,' and then discussing general features about airplanes and this particular type of aircraft, its airline and so forth. By drawing the attention of his students to the problem of air conditioning in commercial aviation, he was then, however, able to redirect the focus increasingly towards geometrical features of the airplane represented by the model. Finally, the students' task was to decide which kind of air conditioning was required for an aircraft of that size. In order to do that, the students had to calculate the volume of the fuselage by estimating its form as an idealized geometrical body.

Objects that come from a non-educational context like packs of copy paper or an airplane model require a far greater deal of performative speech and other guiding practices in order to be transformed into a geometric object. Not only do teachers overcome material resistances as proposed by Mead (1972), they deal with *semiotic resistances* of material objects and try to mitigate the irrelevant associations their students might have. Objects that were already designed to be used in the classroom as knowledge objects (e.g., a geometric model) seem less problematic for teachers. A lot of work has already gone into them in order to minimize any possible non-mathematical or non-scientific associations students might have. Their transformation is (more or less) finished and they no longer lend themselves openly to other methods of usage or interpretation: they have undergone a process of 'stabilization' and 'closure' (Pinch and Bijker 1987). The practical use of these objects is—in Latour's (1996) words—connected to the didactic laboratories in which these objects were designed, constructed, experimented with and fashioned, as if through an invisible force. In this sense, the prism (see above) is designed as a crystal clear plastic object with a smooth surface and straight planes. Nothing detracts from its

[3] Cavalieri's principle states (inter alia) that the volume of two prisms is equal, if the area of their bases and their height are equal.

status as an ideal prism. It is not coloured, nothing is written on it, and it is a textbook example of a prototypical prism.

Disciplinary Vision

When material artefacts are used to convey knowledge, students often focus on non-mathematical features of the object and a lot of work on the part of the teachers to guide student's attention towards relevant features is required. Yet, their use also has an important advantage—students not only learn something about the subject matter, but also what it means to view and think in the manner of the respective discipline. This includes learning which insignificant details can be ignored and how to reduce objects to their mathematical or physical features (see the airplane example). School can thus be seen as an institution facilitating various disciplinary perspectives via its different subjects. In the higher grade levels we often witnessed that teachers were not required to constantly remind students to view a material object in terms of its mathematical or scientific features. The discoursive means of transforming these objects into knowledge objects thus figured less prominently. Instead, students already had internalized the relevant way of seeing, as the following example[4] from a physics course (grade 11; 16–17 years old) illustrates (see also Fig. 1):

> Mr. Hilbert has prepared a demonstration experiment on the horizontal launch of a projectile (a common problem in school mechanics). At the beginning of the lesson the experiment is already prepared on his desk. The experiment consists of a simple metal rod with a spring device attached to it – the device itself holds a wooden ball which can be released from the spring. The topic of the horizontal launch is orally introduced and talked about. Then, Mr. Hilbert channels the student's attention towards the experiment by pointing at and briefly explaining the set-up. Finally, he lets his students know: 'Let's have a look at it!' He releases the spring, and the wooden ball follows a parabolic trajectory, hits the table, rolls off the table and bounces twice on the floor. Mr. Hilbert picks the ball up from the ground and asks: 'What did you see?' A student answers by pointing with and moving his index finger in the air in the manner of an idealized parabolic trajectory. Mr. Hilbert is satisfied ('Exactly'.) and repeats the student's gesture. The idealized trajectory is drawn on the blackboard and a general rule for ballistic trajectories of projectiles is recorded.

The students in this class (grade 11) are accustomed to observing something physically. They know that only certain parts of an observed motion are relevant and that others can be abstracted. By repeating the student's gesture and transferring this idealized motion to the blackboard (see also below), the teacher validates and solidifies this view. Seeing is thus not a simple registration of facts, but a cultural competence that has to be learned. Students acquire 'professional vision' (Goodwin

[4] In this paper, we limit our analysis to demonstration experiments and refrain from discussing hands-on experiments.

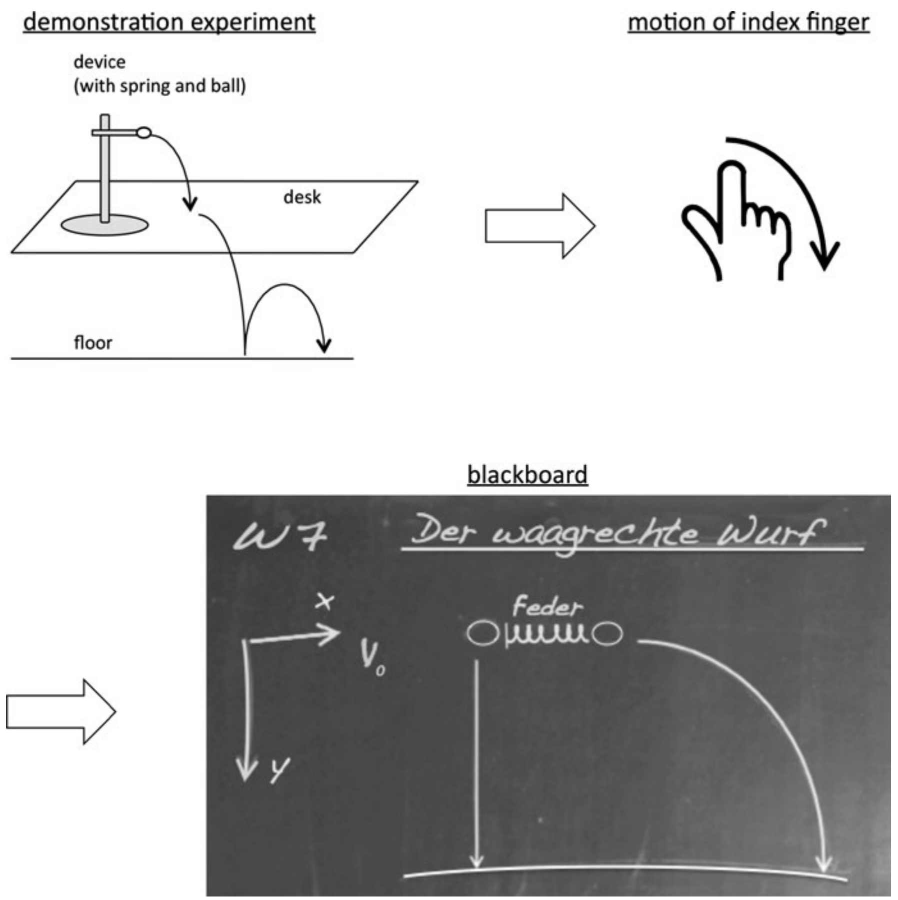

Fig. 1 Disciplinary vision

1994), i.e., in our case the *disciplinary vision* of school physics (see also Stevens and Hall 1998; Lynch and Macbeth 1998). This includes knowing what is relevant and what is not. Classroom discourse is in turn enabled by and, at the same time, reconfigured by objects—their appearance, materiality, and function. Students accustomed to school science know what can and cannot be said about a material object in science class. From a Bourdieusian perspective (Bourdieu 1979; see above), these objects symbolize and bring with them a certain social order.

This can also be seen as a problem. Science in this example is presented as a linear, non-contingent process in which the result is already recorded once and for all in textbooks and in the teacher's notes. Several experiments we observed went wrong and the teachers either tried to repeat them until the desired result was achieved, or explained why students had to record a 'result' that differed from the one observed in the classroom. The status of these knowledge objects is fragile. Teachers and students all act under the assumption that the students genuinely want to find something out about these objects and that the result is unknown beforehand.

As soon as the experiment goes wrong or teachers repel deviant observations, this assumption is threatened and the objects are unveiled as technical objects conveying knowledge in an educational context. Teachers then have to discoursively substitute what the experiment was supposed to show and record it on the blackboard.

The Blackboard

The blackboard is part of the optic system of the classroom. In German mathematics and science classes the blackboard plays an important role: It is continually used to depict mathematical operations for all students at the same time and students are supposed to adhere to the formalized and standardized procedures to solve mathematical problems (Kaiser 1999).[5] As a technical object, the blackboard has certain material features; the mathematical writing depicted on the blackboard is the epistemic object with which teachers and students are concerned. It produces a certain perspective on (mathematical and scientific) phenomena, and it allows for two things at the same time: a phenomenon can be formalized and worked on simultaneously. Consequently, we consider writing on the blackboard to be a pivotal *cognitive instrument* of the transmittal of knowledge.

What can be gained from an ethnographic perspective on blackboards in the classrooms? The participants use chalk, sponges or their hands; things are crossed out and erased, lines are drawn and formulas are written down. Sometimes strange figures are sketched; sometimes there are only words on the blackboard. By presenting the subject matter, the blackboard conserves it, makes it existent and processible. By becoming visible to all, a transformation from oral utterances as well as phenomena demonstrated by objects and experiments to the written form is achieved. Contrary to classroom discourse, which is fast-paced, the blackboard records tasks, geometric drawings, the 'result of the lesson' or pivotal statements, such as 'In the vt diagram, the acceleration is depicted by the gradient' in physics class. The representation on the blackboard thus requires an adjustment of the rules: the 'one-at-a-time'-characteristic of classroom discourse becomes an 'all-at-a-time' characteristic. A phrase that recurs in variations and is often quoted is: 'what's on the blackboard' or 'it's on the blackboard'. Students tend to copy the representation on the blackboard into their notepads, because 'what's on the blackboard is official' (teacher). This attitude mirrors the significance that the teachers attribute to the visualised 'facts'. Students realize how important these are and want to secure the 'facts'. In contrast to the fluidity and partial vagueness of oral classroom teaching, they seem to be 'hard facts'. That is to say, the official character is manifest in the authority the blackboard has among students. This authority is granted to the blackboard, because what is written on it separates itself from its author. It generalises and formalizes what it depicts (cf. Kalthoff 1997: 99–104).

To summarise, the following features are important: first, the temporal dimension of the blackboard. Compared to the oral elements of teaching the blackboard renders objects more permanently visible, available, and workable. Thus, the subject matter

5 For an account of the history and the role of the blackboard in American mathematics teaching see Kidwell et al. (2008: 21–34).

that is up on the blackboard may be continuously altered, expanded, and of course also deleted; the subject matter on the blackboard is *subject to reexamination*. Second, the choreographic achievement: the blackboard aligns the students with what is happening in the classroom, both physically and cognitively. This is apparent, for instance, in students' eyes being 'glued' to the blackboard to copy what becomes visible there. It is also apparent in students' contributions, where comments and questions refer back to the writing on the blackboard. Third, the representational achievement: The blackboard offers a phenomenon to the eye that may be processed both orally and in writing. Visualizing happens at the blackboard and through alphabetical and mathematic signs. Four, authorization: The blackboard does not just show something; it awards meaning to what is written on it: this is correct and important knowledge. The blackboard achieves this authorization by uncoupling the signs produced on it from their author, i.e., it universalizes what it displays. Thus, the technical object that is the blackboard is socially effective. It produces a performative effect, and showing a particular subject matter and rendering it available in a specific way, it constitutes a cognitive instrument.

Writing in Math Classes

Math teachers in German schools systematically and regularly use the blackboard to represent knowledge. The tasks a math teacher proposes (e.g., 'The square root of four point eight divided by the square root of seven point five') are not imaginable, processible and solvable until they are visualised. A purely oral representation remains incomprehensible, because mathematic communication works (mostly) through the visualization of formalized signs and symbols that are used for calculations and modelling. From their respective positions in the classroom, the participants, both the students and the teacher, see identical mathematical signs. Communication in math class consists of these signs, which are spoken or read out loud in a sensible sequence. A teacher who was working on the construction of triangles in the eighth grade (13–14 years) repeatedly insisted that the students solving a math problem at the blackboard express their steps correctly. Otherwise, as he emphasized: 'When incorrect terms are used, it [math] becomes artsy' (teacher). The phrasing that students were to use was drilled. One of these repetitions was: 'I am drawing a part of a triangle CDB using h and the angles'. The terms of mathematic language are practiced intensely. In geometry class, a teacher continually indicated that the students were supposed to say 'Beta,' 'Alpha,' and 'Gamma' when explaining their solution to the math problem. The repetition of the terms in class can also mean that students are interrupted, that teachers recite the terms and students repeat them. As explained by a teacher, the goal is the students' mastery of 'a correct language of mathematical construction'. A particular characteristic of mathematic vocabulary is the fact that it refers to a type of writing in its own right.

Up to this point, this section has shown that the signs and symbols on the blackboard play an important role in math classes. Now, we will go one step further—we will show how problems are represented mathematically (see Figs. 2, 3).

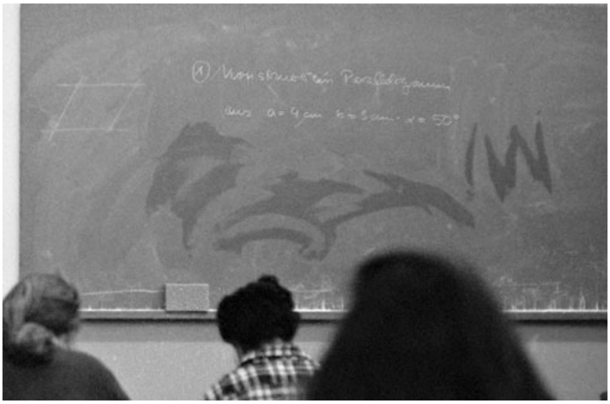

Fig. 2 Mathematical representation on the blackboard I

Both photographs record the representation on the blackboard as a structured image: There are diverse ideographic components such as consecutive numbering, headlines and different line widths. The written text moves from left (beginning) to right (continuation/conclusion); it also records a temporal succession. This diachrony is substituted by synchrony when the representation on the blackboard is complete: The information that was explained step by step can now be seen synchronically and at one glance. In this case, the headline maps out the math problem. It is on one line and the drawing which depicts a parallelogram and the solution to the problem are underneath it. The geometric figure is made up of horizontal, vertical and diagonal lines. Wherever the lines intersect, they form a point which is defined (‘A,’ ‘B,’ etc.). The lines between these points are defined as well (‘a,’ ‘b,’ etc.). The lines extend beyond the points, thus indicating that they go far beyond the frame of the drawing and actually enter infinite space (see Fig. 3). The empty spaces between the elements of the representation, which were placed in a particularly freehanded way in Fig. 3, mark correlations of the elements. Furthermore, multi-channel writing plays an important role: In Fig. 2, a trail sketch is visible. It was erased in the course of the solution of the math problem. Parts of the blackboard are designated as less significant when a teacher uses them for a digression, a side issue or to update the students’ knowledge. This writing, which temporarily becomes multi-channelled, symbolizes the interplay of disjunction and classification in the concrete space provided by the blackboard. This is usually recognized as such by the students.

The representation on the blackboard thus elucidates a certain system in which tasks and accurate visualizations of the solution of a problem portray math as a visualisable, measurable and exact discipline. Furthermore, the threat of the medium vis-à-vis that which is represented becomes clear. The traces of the last erasure announce the approaching end of the representation. In representations on the blackboard, the most important information is marked with a headline and the line width; the solution of a math problem is shown as a consequence of logical steps and visualizations. The blackboard’s clear-cut spatial division refers back to the inner rationalization executed by the teacher writing upon it.

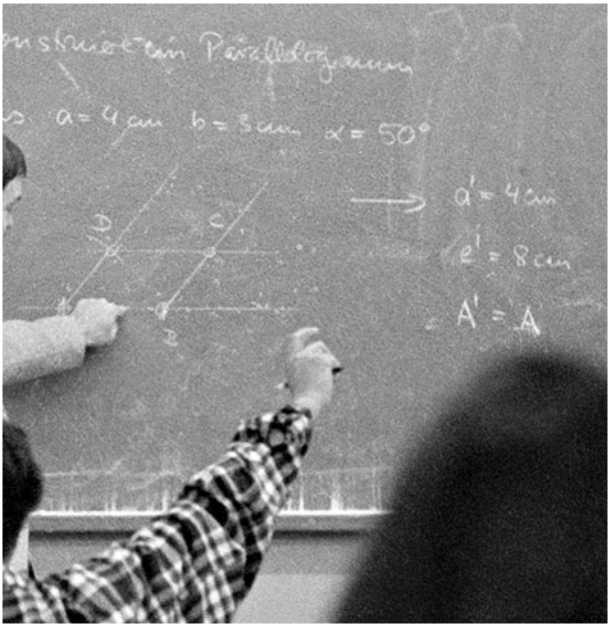

Fig. 3 Mathematical representation on the blackboard II

The Blackboard as Nexus of Writing and Speaking

So far we have treated writing and speaking as separate forms of knowledge representation in classroom teaching. However, we all know that both forms are interwoven; they merge into a reciprocally stabilizing network of representations of knowledge. The blackboard is particularly interesting because it mediates between the technique of showing and writing and the technique of speaking. At the risk of sounding paradox: The *written* representation on the blackboard is, consequently, a discussion, because that which is written on the blackboard is commented on, negotiated and develops through discussion. If that which is spoken and discussed can be found on the blackboard, a peculiar reversal takes place: The representation on the blackboard stands for the author; it is the speaker of his or her knowledge, as described above.

T: We just said that we need a parallelogram that is equal in area. Side a is supposed to remain the same length. What else needs to remain the same so that the area is equal?
Sn: ( ) (3)
T: Valerie
V: Side cee
T: No… Think for a minute, how is the area of a parallelogram calculated? (1) Valerie
V: Um, a times aitch a °for example° ((a x h_a))
T: What is aitch a? ((h_a))

V: The height
T: Right. This side is supposed to remain the same, what else *needs to* remain the same so that the area is equal?
V: The height
L: Exactly, the height, so that's from here to here, right? Put differently, what part of the parallelogram is going to change. There are four points, a, bee, cee, dee ((A, B, C, D)). Which of these four points stays the same, and which four points—which points will change their position. (…) Jan?
J: Well, the angle alpha changes (…), a and bee ((A, B)) stay the same and cee, dee ((C, D)) change
T: Good, and now I'd like to know, (1) we just said that cee and dee's ((C, D)) positions change. (1) Can we still make a statement about the position they will be in (1) after this translation of area, so to speak? (2) Ole can you imagine what it would be like?
O: °nah°
T: Valeria just said that two things need to remain the same, first of all the base, and what else did Valerie say? What else needs to stay the same?
O: °The area°
T: The area is what it says in the task. (1) What else needs to stay the same?
O: ( ) (4)
T: That must have been a good dream you had there. (1) Really nice dreaming. (2) Stephan?
S: The height. (…)
T: Exactly, the height needs to remain the same. So what does that mean for points cee and dee?
(6)
T: Look, we just showed it. The height is the distance between both parallel lines. That needs to remain the same. So then what about points cee and dee? Where do they have to be situated?
Sn: ( ) (5)
T: It's really not *that difficult*. (1) Robert?
R: They both need to be moved towards the right
T: Right. (1) OK? So they will both be on this straight line, on that one, OK?

In the example above, the instructor is teaching the translation of parallelograms (depicted in Figs. 2, 3 above). The treatment of the students who cannot provide the correct answer is not in question here. Rather, the issue of how the visualization of the task facilitates the process of finding the answer to the initial question ('What else needs to remain the same so that the area is equal?') is of interest. The process of the interaction shows that at first the teacher directs the students towards 'the height'; he 'prods' (teacher) the student towards the answer by excluding other requirements and therefore proposing the process of elimination ('cluing'; see McHoul 1990). After Valerie has provided the correct answer, the teacher converts the question to the translation of points D and C on the straight line, demonstrating this process on the blackboard. The students are meant to recognize that points D and C must be moved to the right on the straight line if the height remains consistent. The student Robert provides the correct answer.

It is of utmost importance that the teacher continually refers back to the drawing on the blackboard throughout the interaction. He expands and finally completes the drawing so that a thickly framed, new parallelogram that fulfils the requirement of being equal in area becomes visible (see Fig. 3). In addition, the teacher repeatedly gesticulates towards the drawing, which he presumes is collective knowledge (because it is visible). The conception is that the knowledge on the blackboard is public and shared knowledge because it was presented in front of an audience; it is short-lived and in progress because it can be corrected and erased persistently. Yet the blackboard is neither identical to books or the students' notepads, nor to oral exchange, but rather an independent form. Writing on the blackboard and classroom discourse must be considered as two techniques in their own right. Both assume a specific role in the representation of knowledge. The principle of literality can be understood as a cognitive "artificial limb" which evokes processes of thinking and of imagination.

Knowledge which develops on and through the blackboard must be stabilized continually by talk, the bodies and the glances of the participants. That is, public knowledge develops gradually and is in need of persistent stabilization. In other words: The blackboard coordinates eye, voice and hand.

Conclusion

Classroom discourse and material objects are fundamentally intertwined in school lessons. Knowledge objects have to be introduced and turned into objects capable of conveying knowledge by linguistic means. While some objects are better suited to function as knowledge objects, mundane objects often have to be carefully introduced by teachers. Discoursive means of transforming and stabilizing these objects are even more important. Material objects are thus not simply present in the classroom, but have to be embedded within the language game of the school lesson. Knowledge objects in turn enable but also constrain classroom discourse. Students have to learn how to see mathematically or scientifically by observing specific objects—what can be said about them is limited.

As far as the blackboard is concerned, this paper shows that the blackboard stabilizes classroom discourse. Moreover, it turns fleeting classroom discourse and scientific observations into recordable knowledge. To put it more succinctly: without (mathematical) writing on the blackboard or without demonstration experiments in science classes there would be nothing to talk about. It seems that, through an invisible thread, the classroom discourse is linked to material objects and signs which are the media of knowledge representation within classrooms.

In more general terms, our analysis also illustrated the interplay between practices and objects, between interactivity *and* interobjectivity. It thus proposes an intermediary perspective to avoid the shortcomings of both approaches. While interactionism emphasizes how human actors use and thus transform material objects, it neglects the role of things as mediators of practice which are capable of transforming human actors and actions. Likewise, the posthumanism of ANT loses sight of creative and divergent practices that human actors employ when dealing with objects. While more recent developments in ANT acknowledge the fluidity of material objects (e.g., De Laet and Mol 2000; Law 2002), they still often fall into the pitfall of symmetry: semiotic indifference. The semiotic view of ANT treats material objects, bodies, signs, human actors and their practice alike. It thus opens up the analytic perspective for research for a number of hitherto neglected participants of practice. Yet, the different materialities of these elements of practice are often left unexplored. Ultimately, an approach is needed that integrates material objects as mediators of practice among others (e.g., bodies and signs; see Kalthoff 2011) and that is open to an embodied and situated view of practice in which the sensuous qualities of material objects are recognized. In that way, we see material objects as mediating interaction by inviting some ways of dealing with them, while at the same time inhibiting others as proposed by postphenomenology (Verbeek 2005). Interobjectivity thus lies not so much in the agency of objects but rather in their ability to invite human actors to use them and act with them, to perform their 'scripts' or to ignore them.

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