Grappling with the Not-Yet-Known

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Abstract: The importance of shared artifacts as means for learning has been widely acknowledged in the learning sciences as well as within the field of CSCL. However, there is no consensus on the actual roles these artifacts are playing in processes of (collaborative) knowledge creation. In this paper we argue that the prevailing theoretical accounts block sight for important epistemic processes and also hinder a deeper understanding of the material qualities of use as they focus on the explication of what is known rather than on what is not known yet. Drawing on an ethnographic study in a design studio course on industrial design, we depict the use of design artifacts in a set of epistemic patterns. Based on the conclusion that these artifacts can be understood as objects used to come to terms with the unknown, we discuss potential implications for CSCL systems aimed to foster collaborative knowledge creation.

Keywords: knowledge building, knowledge artifact, case study, tool design

Introduction

The development of tools in support of collaborative knowledge creation cannot be decoupled from the striving for a better understanding and theorization of the ways people actually work together to produce new knowledge (e.g. Farooq, Carroll & Ganoe, 2005) as well as the role of the artifacts used in these processes (e.g. Eckert & Boujut, 2003). Many recent computer-supported collaborative learning scenarios engage learners in working on ill-structured and open-ended problems, be it in the fields of research, engineering, or design. Respective scenarios have challenged pre-established conceptions of the artifact, as a resource of information or as a means for communication (cf. Enyedy & Hoadley, 2006) and raised the question of the epistemic role artifacts are playing in processes of inquiry, design, and knowledge creation. Stahl, Ludvigsen, Law & Cress (2014) most recently positioned artifacts as central to CSCL as, among others, collaborative learning essentially might be oriented towards and result in the creation of knowledge artifacts. However, despite the recurrent call for a deeper understanding of the function of artifacts for collaborative knowledge creation, there is an inclination to conceive respective artifacts, be them a theory, a model, a research paper, or a designed object, as an externalization or embodiment of what is known (cf. Bereiter, 2002; Stahl, 2006; Kimmerle et al., 2010). Even if it is emphasized that the respective artifacts "are in the process of being developed" (Paavola & Hakkarainen, 2009, p. 84) and therefore tentative, incomplete, or ambiguous, they are primarily understood as means to explicate, reify, and convey ideas about what is or should be. However, these conceptions inevitably foreground issues that are already expressible, or even agreeable, including the problems to be solved and the questions to be answered. In doing so these conceptions bracket out all those instances in which artifacts are created and used to actually figure out what is not known yet, where people engage in situations that are essentially uncertain and open-ended, and where artifacts cause puzzlement and surprise.

Against this background we argue in this paper that to deepen the understanding of the role of artifacts in processes of knowledge creation, we have to overcome representational notion of artifacts but to reconsider them as artifacts of inquiry, essentially aimed to come to terms with what is not known yet. Drawing on the notion of epistemic artifacts as suggested by Knorr-Cetina (2001) and Rheinberger (1997, 2006) as well as related work in fields of scientific modeling (Knuuttila, 2005) and design research (Gedenryd, 1998) we will sketch a conception of epistemic artifacts as objects in and through which participants circumscribe, raise awareness, and bring to the fore the limitations and lack of knowledge they deem of relevance for the inquiry processes they are engaged in. To illustrate the fact that representational conceptions of knowledge artifacts are not capable to account for a variety of processes that are essential to certain forms of knowledge creation, we depict and discuss a set of epistemic patterns we found in an ethnographic study of a design studio course on industrial design. Based on the theoretical considerations and empirical findings, we finally discuss potential implications for CSCL systems aimed to foster knowledge creation.

The contributions of this paper to the field of CSCL are threefold. First, on the theoretical level the paper delineates some of the limitations inherent to representational notions of knowledge artifacts. Second, in

providing examples on the use of artifacts in an educational setting it raises awareness for the commonly intricate nature of an artifact's use and its material entanglement. Third, the paper challenges current approaches to the design of CSCL systems that downplay or bypass the material nature of many artifacts and respective knowledge practices.

Knowledge artifacts: Two incompatible conceptions

In the following we briefly review the theoretical accounts of knowledge artifacts that figure prominently in the field of CSCL and then contrast these with a non-representational account of artifacts. Our focus is on those theories that explicitly deal with the notion of knowledge artifacts. Even though these accounts do so under somewhat different labels, they all posit that a particular type of artifact is at the center of collaborative knowledge creation.

Knowledge artifacts in theories of CSCL

In his theory on knowledge building Bereiter (2002) develops the notion of conceptual artifacts, "which are human constructions like other artifacts, except they are immaterial and, instead of serving purposes such as cutting, lifting, and inscribing, they serve purposes such as explaining and predicting" (p. 58). These conceptual artifacts, which include for example "ideas, facts, theories, algorithms, designs, problem formulations and problem solutions" (p. 64), are conceived as immaterial yet objectively existing entities. While Bereiter argues that it is the "thing-like" nature of these artifacts, which "makes it possible to treat them as objects of study and discussion" (2002, p. 66), he makes a clear distinction between conceptual artifact as such and its material representation, e.g. in the form of text or graph. This distinction becomes most evident when he states that: "When we argue about a theory or design we are not arguing about a piece of paper or about the particular words or lines on the piece of paper. We are arguing about the abstract knowledge object of which those words or lines are but one possible representation" (ibid, p. 64). This conception however implies that a conceptual artifact is essentially independent of both the conditions of its own production as well as the material carriers that embody or represent it. Thus the material artifacts (physical or digital) are seen as partial representations of some abstract conceptual artifacts the students or knowledge workers are trying to create or improve.

A quite similar figure can be found in the accounts provided by Stahl (2006) as well as Kimmerle et al. (2010). Stahl (2006) also emphasizes the role of artifacts and argues that "the knowledge-building process can be conceptualized as the construction of knowledge artifacts, involving physical and symbolic artifacts as starting point, as medium, and as product" (p. 239). Stahl avoids to make a strict distinction between conceptual artifacts and their material embodiments as suggested by Bereiter. In fact, content and form appear to be somehow intermingled in Stahl's conception of knowledge artifacts when he introduces "a verbal problem clarification, a textual solution proposal, or more developed theoretical inscription" (p. 3) as examples. However, when turning to the role of artifacts he conceives them as "embodiments of meanings that have been embedded by the artifact designers or creators; new users of the artifact must bring those meanings back to life" (p. 294). Hence, also in this account there is supposed to be a meaning embodied or represented in the knowledge artifact that is independent of its material carrier.

Kimmerle et al. (2010) in their co-evolution model of cognitive and social systems more recently also emphasized the role of what they labeled as epistemic artifacts. In focusing on social software such as wikis and social-tagging system they stipulate that "collective knowledge manifests itself in shared digital artifacts" (p. 10). They conceptualize the work around these epistemic artifacts as continuous processes in which individuals on the one hand externalize cognitive concepts and articulate their knowledge while on the other hand they internalize and draw on the information entailed in the epistemic artifact. Both internalization and externalization require a translation in which people have "to couch their cognitive concepts in words" and "to consider the information which is already available in an artifact in order to integrate their own thoughts adequately" (Kimmerle et al. 2010, p. 11). Again the material artifacts such as wiki pages and tags are basically understood as more or less arbitrary carriers of some information articulated and retrieved by its users.

In their model of trialogical learning Paavola and Hakkarainen (2009), finally, explicitly emphasized the concrete and material nature of the shared objects knowledge creation processes are targeted towards. They highlight the evolving nature of what they call trialogical objects, which comprise of such diverse things as "knowledge artefacts, practices, ideas, models, representations, etc." (p. 84), and the iterative processes through which these objects are developed and modified. However, the relation between knowledge artifacts, practices and externalized ideas and representations remains opaque in this account. If, for example, a joint research article qualifies as a shared object of knowledge creation (ibid. p. 86) we have to concede either that the research article is a self-contained entity or that it refers to and in this sense provides a representation of some other object, be it an empirical phenomenon or a conceptual artifact. Even though it is contrary to Paavola's and

Hakkarainen's stated intentions, their conception of trialogical objects easily boils down to a representational account of knowledge artifacts as something "that embodies the understanding, meaning, or knowledge that has been constructed" (Damşa, 2014, p. 254).

In summary, despite the different schools of thought the above concepts of knowledge artifacts are based on, they all imply that the material objects that are produced and used in the processes of knowledge creation are essentially representational devices, be it that they represent some conceptual artifact, some meaning, understanding or knowledge. In this sense, all of them are inherently focused on what is already known rather than on what is not known yet. The underlying claim, that in our understanding renders these accounts problematic, is that there is a kind of knowledge that can be effectively separated from the conditions of its own production and its material embodiments.

Knowledge artifacts as embodiments of the not-yet-known

Aiming to sketch an alternative perspective on the role of knowledge artifacts in processes of knowledge creation we draw on the conceptions of epistemic objects developed by Rheinberger (1997, 2006) and Knorr-Cetina (2001).

Based on the assumption that scientific research essentially takes place at the borders of the known and the unknown, Rheinberger (1997, 2006) introduced the concept of epistemic objects, which embody what one does not yet know. In Rheinberger's conception these epistemic objects, which he alternatively labels as the objects of the research or epistemic things, are a part of historically evolving experimental systems the researchers are engaging in. These experimental systems, in which epistemic and technical objects are intrinsically entangled, are not conceived by him as apparatuses to test ideas or provide answers but essentially as arrangements in which questions, which are not yet raised beforehand, materialize. In this sense Rheinberger's main intent is to position epistemic objects in the context of discovery rather than justification.

In building on Rheinberger's ideas, Knorr-Cetina (2001, p. 181) stresses the epistemic object's "changing, unfolding character – or its lack of 'object-ivity' and completeness of being, and its nonidentity with itself" and introduced the notion of "partial objects" as material instantiations of the unfolding epistemic object. For Knorr-Cetina these "partial objects" might take the form of "partial simulations and calculations, technical design drawings, artistic renderings, photographs, test materials, prototypes, transparencies, written or verbal reports, and more" (p. 182). However in her conception, the "partial objects" are neither a referent to nor a representation of the epistemic object but they have a "signifying force" due to their "internal articulation" (Knorr- Cetina, 2001, p. 183). The upshot of this conception is that the epistemic objects we are interested in cannot be separated from the partial objects used to imagine, simulate, represent, measure, or realize just these objects. Hence, we are inclined to conceive all those material artifacts that are produced and used in processes of knowledge creations as "partial objects" rather than as representations of some knowledge object. Following Knorr-Cetina (2001) we concede that the significance of the respective artifacts is not so much in the meaning or information inscribed into them, but in "the pointers they provide to possible further exploration" (p. 183).

Similar notions of artifacts as means to come to terms with what is not yet known have been put forward in the fields of scientific modeling and design research. For example, Knuuttila (2005) suggested to re-consider scientific models as "investigative instruments" or "productive things" which are partially independent of both the domain theory (or formal domain knowledge) and the world. As purposively created artifacts, she argues, modelling should not be treated as an isolated activity but as an integral part of more overarching practices of scientific inquiry or product development. In turn that implies that the models itself are entangled with the object of inquiry. Furthermore, she argues, models have, besides their conceptual, a material form and, therefore, are subject to the affordances and constraints of the medium used for modelling. For example, tools might enforce a certain degree of formality but also afford and constrain certain forms of expression. Finally, the creation and manipulation of models, under this conception, can itself result in new knowledge and even constitute new realities. Knuttilla points out that models are often not just used to abstractly represent a target system but to actively design or intervene in the target system.

Being concerned with the apparent gap between prescriptive accounts of the design process and actual finding of empirical studies Gedenryd (1998) came to quite similar conclusions. Rather than understanding design artifacts as intermediate outcomes or end products of the design process, he conceives them as "inquiring materials: working materials with a cognitive purpose" (p. 149). For Gedenryd design artifacts, be them sketches, prototypes, scenario or simulations, are "means for the inquiry that design is". Just as in Knuuttila's non-representational conception of models Gedenryd also stresses that the design artifacts are the very means of working on a problem, that the material they are made of severely matters and that they are closely entangled with evolving design objects themselves.

In a nutshell, what sets the latter accounts apart from the conceptions of knowledge artifacts in current theories of CSCL is (a) that the significance of these artifacts, be them questionnaires, models, sketches or prototypes, is their incompleteness and uncertainty that opens up room for surprise and future explorations, (b) the emphasis on the material qualities of these artifacts as well as (c) the constitutive entanglement with the object of inquiry.

A case study on the use of artifacts in a design studio course

To illustrate the fact that representational conceptions of knowledge artifacts are not capable to account for a variety of processes that are essential to certain forms of knowledge creation, we draw on an ethnographic study of a design studio course on industrial design. The case study was carried out in a design studio setting at the Muthesius Academy of Fine Arts and Design in spring 2013. The course we followed was part of the study program on industrial design with a specialization on Interface Design. It was conducted by a professor and a research assistant. Eleven bachelor students in their 5th semester and six master students took part in the course that lasted from April to July, spanning a period of 14 weeks. Under the overall theme "simulation/simulator" the students were asked to define and carry out individual design projects. All students enrolled in the course were included in the study. We assume, that creative design can be understood as a proper form of knowledge creation, in that it is inherently geared towards the creation original and novel artifacts, systems and services.

To develop an understanding of the creative practices enacted within this setting we drew on a collection of data sources, including (a) observations of the interactions between the students and the teaching staff during the contact hours, (b) students' narrative accounts of their working process, either voiced in students' interactions with the teaching staff or in informal interviews carried out by the research team, and (c) the material arrangements and artifacts present and utilized in the design studio. Data was recorded in the form of extensive field notes supplemented by photos and audio-recordings when feasible. A total of three observers conducted over 64 hours of site observations, taking part in more than 90 individual feedback sessions as well as the students' final presentations. In parallel, the observers wrote memos following the sessions they attended and conducted a workshop with the students and the professor aimed to elaborate on the utilization of design artifacts in the middle of the term. Each of the observers has at least two years of teaching experience in a design related domain. Informed consent was obtained from all participants including the teaching staff.

To identify common practices within the setting but also to trace variability, each of the students' projects has been treated as a distinct case in the analysis. Field and interview notes were organized into chronological case logs. Using an abductive approach, case logs and memos were used to surface patterns of interactions, which were then iteratively tested against the other cases until a stable set of patterns was found. We took patterns of interaction as a descriptive format in the attempt to shed light on the constantly unfolding network of interactions between actors and artifacts in the given setting. They describe recurring ways of how actors cope with and transform the situations they are facing. Towards this end patterns are supposed to provide middle-level abstractions in that they capture (situated) regularities in a form that is potentially verifiable and intelligible to other practitioners (Dearden & Finlay, 2006).

Patterns geared towards the advancement of ideas

The analysis of the case logs resulted in the formulation of twelve patterns, which synthesize the observations throughout the 14 weeks of students' project work. Even though not every pattern was observed in each case, the set of patterns was assumed to be characteristic for this context in that each of the patterns was instantiated in at least 50% of the projects, often repeatedly. In the following we focus on a subset of these patterns, namely those four that were most directly related to the advancement of students' project related ideas. For an overview of the entire set of patterns the reader is referred to Richter, et al. (2014).

Playing with ideas

Especially in the early stages of the design process the students and the teaching staff were recurrently engaged in highly explorative discussions on yet tentative design proposals. These discussions were not unlike brainstorming sessions in that they were associative and non-judgmental. Yet, the discussions were primarily geared to open up different perspectives rather than to produce a wealth of ideas. In sharing and taking up these "half-baked" ideas in an explorative and playful manner, the design proposals were widened and approached from multiple perspectives. In doing so the potential of the yet vague idea was collaboratively checked, not as something to be approved or rejected, but as a stimulus and springboard for more advanced ideas.

The students reported on similar kinds of explorative discussions also with fellow students, friends, relatives and other acquaintances outside the course setting. In the course context these situations occurred when

something was discussed, which was „not fleshed out, but just mulled over“ as a student put it, or after an official feedback in an informal follow-up discussion. This kind of exchange about ideas was usually triggered by the students and assessed as crucial for the concept phase, both by the students as well as the instructor. In fact the instructor recurrently asked the students to share even preliminary ideas and strive for feedback.

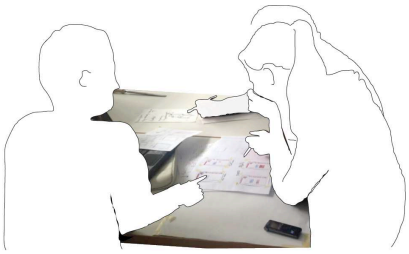

Figure 1. A student ponders with the instructor and the research assistant on an idea

In the concerned but also playful exploration of ideas, artifacts were used in two main ways. On the one hand sketches, scribbles or found objects were used to supplement the verbal presentation of the initial idea, often riddled with gestures and metaphors. On the other hand, the presented artifacts were frequently edited, commented, augmented or juxtaposed with newly created artifacts, esp. sketches, in the course of the subsequent discussions. The artifacts were used to ground the discussion but also to express ideas more directly as they evolved in the process. As the ideas to be discussed were fuzzy and preliminary, even to the students themselves, the artifacts were able to provide tentative and approximate objectifications at best.

Yet rather than being precise and definite, their value seems to be based on their capability to trigger associations and open up alternative options and perspectives. In fact highly elaborated presentations repeatedly blocked the exploration and scrutinization of the underlying ideas. The vagueness and ambiguity of artifacts hence provides an important resource to explore the design space and avoid fixation on premature solutions.

Making ideas tangible

Throughout the various stages of the design process the students have tried to make their ideas tangible, be it the form of interface sketches, moodboards, mockups, interactive prototypes or video recordings and animations. The phenomena the students were concerned with ranged from visual aesthetics, over haptic and auditory impressions, to modes of interaction and their integration of all these into coherent experience. The need to make ideas tangible especially arose when participants were dealing with concepts or ideas that entailed complex and often bodily experiences, which were hard to grasp and communicate otherwise. For example, a student working on an interactive installation realized that the physical setup, which was meant to be surprising was in fact assessed as partially frightening by the test users, prompting him to do further experiments with different setups. Or a student working on a mobile app was searching for a proper visual metaphor conveying the message “I am glad [that you contacted me] and that’s why I tell you how you can come to me.”

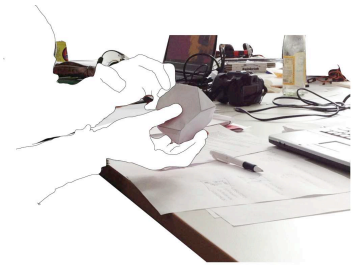

Figure 2. A student explains the envisioned interactive mechanisms with a paper mock-up

The materialization of a concept or idea usually took the form of some kind of (rapid) prototyping, in which the students learned about the experiential qualities they wanted to preserve or avoid. The tangible outcomes were then introduced to their fellow students, the instructor or some test users and tested. The actual try-out was then followed by a debriefing, in which the interlocutors tried to couch their experiences and impressions verbally. In some instances the student as well as the lecturer also used gestures and bodily postures to mimic certain experiences in the absence of tangible artifacts.

The production of tangible artifacts enabled participants to experience certain qualities of the design concept and hence added to the grounding of the design process and the interactions among the participants. This common ground, based on shared experiences, provided reference points for design decisions and furthered the development of relevant qualities of the design product and its use. Asking the students to materialize their ideas the instructor explicitly took account of the fact that many phenomena relevant to the quality of a (new) product are only insufficiently captured in abstract representations but require first-hand experience.

While the tangible objects are at best proxies for the envisioned design product, their epistemic value in this context seems to be due to the kind of first-hand experiences they provide, experiences that are more concrete and precise than any (verbal) representation would be. These experiences, which are to some extent partial, are also bound to the materials used.

Reflective prototyping

As the design concepts matured most of the students also started to develop various kinds of interactive prototypes. These prototypes ranged from simple click-through dummies, over interactive installations towards functional hard- and software-systems. While some of the prototypes where used for presentation purposes, the majority of prototypes were created to probe into the effects a certain design decision would have or whether a certain idea would be feasible at all. The issues that gave rise to the development of the prototypes were usually quite specific to the design concept, rendering existing know-how or expertise more or less futile, so that practical experimentation appeared to be a useful if not the only viable approach available. The instructor stressed the probing function of prototypes also in the discussions with the students: „When you develop prototypes] it is particularly important, that you can say that there is something that you can figure out.“

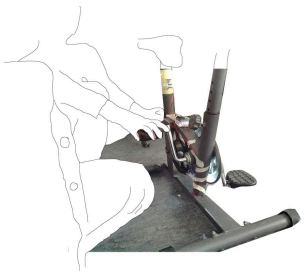

Figure 3. A student presents his most recent prototype: “This is just a prototype, so that it’s possible to see how it is to steer or to change speed.”

Rather than providing a means to communicate or showcase a design idea, this kind of reflective prototyping was understood as an open-ended yet also focused form of inquiry in that the prototype should shed new light on issues relevant to the project. While in some cases the prototypes were used to collect feedback from others, the creation of the prototypes itself recurrently turned out be a source of insight itself, be it that the students where unsatisfied with the result, or that new issues and ideas turned up.

To retrieve timely results, prototypes were often made of malleable materials such as cardboard, styrofoam or recycled material which are at the students’ disposal. Describing the components of a physical interface prototype a student explained: “I used hair gel, it was the only thing I had at hand.“ Nevertheless, students often spent considerable resources on the production of the prototypes and also engaged their fellow students in the production process.

The prototypes, as used here, are not just deliberate attempts to embody some abstract design concept but means to deepen the understanding of the design space. In this respect, a particular challenge for the students is to find materials and formats that provide proper answers to the questions they are concerned with.

Imaginative walkthroughs

In all stages of the design process the students and the teaching staff carried out imaginative walkthroughs in which they talked through the different steps a potential user might encounter when interacting with the envisioned design product. Aspects of the design that were covered in these walkthroughs ranged from users activities, emotions and experiences, over the coherence, adequacy and usability of the suggested interfaces to the expected outcome and impact of the entire product. A primary aim of these walkthroughs was to develop an understanding of the scenarios a potential user might find him/herself engaged in and check the implications of the respective design decision made or to be made.

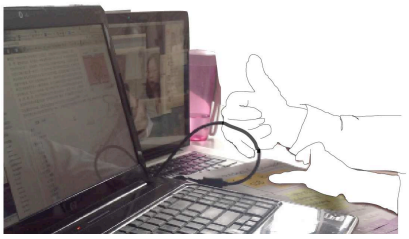

Figure 4. A student and the instructor talk through an envisioned usage scenario.

Imaginative walkthroughs were either carried by the students themselves or in a collaborative manner with the teaching staff or fellow students. In the first case, the students created personas, scenarios and storyboards or engaged in some form bodystorming or self-experiment to push their concept. The insights were then presented to others later on. In the other case, the imaginative walkthrough was used as an ad hoc approach to further the mutual understanding of the intended scenarios and explore design implications.

To carry out an imaginative walkthrough, at least a minimal account of the design or the foreseen interaction sequence was used as a prompt, which eventually was expanded or altered in the course of the walkthrough. If tangible artifacts were used, they were often quite partial. For example in one of the sessions the instructor engages with a mockup of an interactive pen-device, he holds it in different positions and draws in the air while talking through an envisioned scenario. In other cases the walkthroughs were carried out without any tangible props in a purely verbal manner or based on a sequence of interface sketches.

Due to their narrative nature the imaginative walkthroughs are neither definite nor comprehensive, but itself open to interpretation. However, just because of their scrappiness and subjectivity they appear to be versatile means to develop a more empathetic understanding of a user's situation as well as to identify potential problems and bottlenecks.

Discussion

Being aware of the fact that the patterns of interaction we described above are quite sketchy and do not fully account for the overall complexity of the design efforts the students have been engaged in, these patterns however closely match the kind of inquiring engagement with design artifacts that Gedenryd (1998) has emphasized. In the patterns we also see recurrent references to the inquiring materials that he mentions, be it sketches, prototypes, scenarios or various forms of simulations. What all the four patterns have in common is that they explore into the design space aiming at new insights regarding potential constraints or potentialities. Even though the patterns address somewhat different situations, they all entail a momentum of uncertainty and lack of knowledge. In playing with ideas, the participants typically start from a vague idea or incident, which is then explored in an open-ended, associative, and non-judgmental manner. In making things tangible, they try to express ideas and experiences that are hard to couch in words and formula. In developing prototypes they explore into the feasibility of an idea as well as unforeseen (side-)effects of different design options and in the imaginative walkthroughs they simulate an assumed usage scenario trying to develop an empathic understanding of the foreseen target population and their experiences.

Trying to reduce all these efforts to the development of a clearly identifiable knowledge object in the form of a project report, presentation or the designed product itself, consequently is misleading as it implies that the insights gained throughout the design process would essentially crystalize in any of these artifacts. It ignores the epistemic value of all the sketches and prototypes that were consciously dismissed, it implies that a design artifacts has a specified meaning independent of its actual enactment in a certain usage scenario and that there is some underlying idea that could be separated from its material form. The idea that there are some artifacts in which knowledge becomes "frozen" (Damşa, 2014) discounts the inherent "'situatedness' [which] locates the design process in a world which is already crammed with people, artifacts, and practices, each with their own histories, identities, goals and plans" (Fallman, 2003, p. 227).

Implications for CSCL

While the focus of our case study has been on (collaborative) design, we believe that the findings apply to a much boarder class of knowledge-creation processes. Irrespective of whether we talk about the design of an innovative product, some basic research carried out in a laboratory or an ethnographic field study, we cannot separate the knowledge object from all the partial objects that are created and used along the way.

Apart from theoretical implications, we belief, the conception of knowledge artifacts as partial objects also has more direct implications for CSCL systems aimed to foster knowledge creation. First, in addition to tools that foster rational discourse and argumentation, there is a need for tools that allow for open explorations and surprise in that they allow collaborators to express and ponder on ideas that are inherently incomplete, uncertain and ambiguous. Second, CSCL systems have to carefully account for the material qualities of the partial objects that are used in the kind of knowledge-creation processes to be addressed. In particular it has to be acknowledged that textual accounts as well as means for visual inspection and analysis are often insufficient to come to terms with the complexity and subtlety of the phenomena and ideas often at stake in processes of research and design. Towards this end new means are needed allowing collaborators to elaborate on and share their ideas in a variety of media irrespective of whether these are physical or digital. Finally, attention needs to be drawn to the close entanglement of the technical and epistemic objects. Technical tools, including CSCL systems, are by no means neutral to the ideas we express and the phenomena we describe. This not only entails their semantic and syntactical affordances, but also their aesthetical and experiential qualities.

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