Reasoning with representations: Exploring students' interactional sense-making in computer-based inquiry settings

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Abstract This paper reports on a study of students’ reasoning with representations within a computer-based learning environment aimed at supporting students’ collaborative inquiry learning. Taking a socio-cultural approach, the aim of this paper is to explore and understand how students use canonical models of solar panels in settings where they engage in collaborative, computer-based inquiry learning. By means of detailed analyses of students’ interaction taking place in a student project about energy and heat transfer, we demonstrate how representations become structuring resources in the students’ process of conceptual sense-making. Analyses of student group interactions show that the representations in use become central in teacher intervention settings, in that both the teacher and the students use the representation as a resource for constructing shared understanding of scientific concepts. Furthermore, the analyses show how representations become important by enabling the students to negotiate and make sense of explanations provided by the teacher, and by enabling students to provide conceptual explanations in new settings with novice peers.

Key words Conceptual sense making * inquiry learning * interaction analysis * physics * representations * secondary school * socio-cultural perspective
Introduction

In keeping with the extensive digital and technological innovations of recent decades, a variety of new visualizing opportunities for presenting and engaging with complex scientific concepts have emerged that today constitute central parts of our everyday and professional lives. These visually representational forms also characterize the digital resources that students are introduced to for learning purposes in the setting of school science. Several computer-based learning environments have been developed with the aim of engaging and supporting students in scientific inquiry (de Jong, 2006; Quintana et al., 2004). A common feature of many of these computer-based inquiry environments is that they introduce students to abstract and complex scientific concepts by means of new forms of representations such as interactive animations, models and simulations, as well as offering supplementary tools and sources enabling new combinations of visual and textual representations (diSessa, 2004). In this sense, computer-based inquiry environments have qualities that can contribute by making abstract scientific inquiry more tangible for students (Edelson, Gording, & Pea, 1999; Linn, Davis, & Bell, 2004; Kluge & Bakken, 2010).

Much of what we know about students’ learning with representations is derived from experimental or quasi-experimental studies focusing on the effect of various representations on individual student performances. Another common feature of these studies is that most of them are carried out in laboratory settings (Ainsworth, 2006). In addition to building on results from these studies, we argue that a process-oriented approach is needed in order to gain a deeper understanding of the impact of representations in collaborative learning settings. There are few, but some, process oriented studies focusing on students’ learning with representations in collaborative learning settings (Suthers & Hundhausen, 2003). A common finding from most of these studies concerns the considerable interpretive effort that the students need to undertake in order to make sense of scientific concepts, as well as the representations to which they are introduced. Still, there is a fair consensus on the positive implications of students’ engagement with representations in collaborative learning settings. Positive findings are, for instance, that visual tools such as graphs and matrixes have a positive impact on student discussions and end products (Suthers & Hundhausen, 2003), that peer collaboration has a positive effect on the abstraction level seen in students’ self constructed representations (Schwartz, 1995) and that representations are important collaborative resources supporting concept-oriented discussions among peers (Furberg & Arnseth, 2009; Kozma, 2003). The present study aims at adding to this body of research by performing in-depth analyses of students’ use of representations in naturalistic computer-based collaborative settings.

Within each expert domain there are canonical representational forms, that is, representations that have become the normative way of displaying and visualizing scientific concepts (diSessa, 2004). This study directs analytical attention not only to the interpretive work that needs to be undertaken by students in order to make sense of scientific concepts, but also to the canonical representations presented to them in school science. The concept of ‘interaction trajectory’ is essential for how we view the process of learning, and for the way we conduct our empirical analyses in this paper. Interaction trajectory refers to interactions taking place over a period of time (Dreier, 1999; Ludvigsen, Rasmussen, Krange, Moen, & Middleton, 2011). By following students during their learning activities, we aim to display how representations become important conceptual and social resources in different phases of students’ collaborative learning processes.
The theoretical perspective taken in this paper draws on a socio-cultural approach to learning and reasoning with representations in collaborative computer-based settings (Säljö, 2005; Vygotsky, 1978; Wertsch, 1991). The focus, then, is not on the effect of representations seen in relation to student performances, but rather on the very process where representations are in use – that is, an analytical focus on the students’ interactional sense-making, as well as their interaction with the representations at hand (Greeno & Hall, 1997; Roschelle, 1996). This implies that representations are seen as potential discursive resources in students’ learning processes (Goodwin, 1997; Latour, 1987; Roth & McGinn, 1998). In order to display how representations become important conceptual and social resources in different phases of students’ learning processes, as well as demonstrating how this can be studied, we perform detailed analyses of sequences from the interaction taking place in one student group while working on a science project about energy and heat transfer. The participants were upper secondary school students (aged 15 – 16 years) and their teacher. The central resource for introducing students to the energy and heat transfer curriculum was the CSCL environment SCY-Lab, in addition to Internet resources and textbooks. The following research questions will be addressed:

- How do collaborating students engage with representations presented to them in the computer-based inquiry learning environment?
- In what ways are the representations functioning as structuring resources in the students’ evolving process of conceptual sense-making?

**Representations as discursive resources in students’ meaning making activities**

From a socio-cultural perspective, learning is regarded as dynamic and dialogical meaning making process between interlocutors (Linell, 1998). A central assumption is the emphasis on the mediating role of semiotic and cultural tools (Vygotsky, 1978; Wertsch, 1991). In their interaction, participants try to interpret and make sense of situations, actions and scientific concepts. At the same time, they make their own interpretations visible and observable to other participants. In this sense, language is conceived as the most important tool for making sense of the world, of human practices and ideas and a tool that mediates thinking and reasoning (Vygotsky, 1986). Talk and discourse is therefore conceived as a ‘social mode of thinking’ (Mercer, 2004). Meaning is dialogically constituted in specific practices, and meaning making involves complex interactions between people, resources and the organization of the setting (Stahl, 2006). An important part of human conduct and learning processes is the employment of various types of material tools and representations (Säljö, 2000). Tools and representations can be seen as cultural artefacts that store knowledge and social practices developed over generations (Cole, 1996). This implies that representations such as graphs, visualizing models or diagrams are developed in order to display and represent experts’ knowledge about objects, processes or phenomena. The knowledge and practices stored within the representations are what students interact with when utilizing representations in learning activities (Säljö, 2000). However, as important as being resources for displaying expert knowledge, representations are also resources for analysing information, communicating ideas and coordinating interaction in collaborative problem-solving processes (Roschelle, 1996; White & Pea, 2011). In this sense, representations can be seen as possible discursive resources in students’ scientific sense-making (Linell, 1998; Roth & McGinn, 1998).
In this perspective representations are seen as *inscriptions* (Latour, 1987; Roth & McGinn, 1998), meaning that visual displays, simulations and models are seen as signs that are materially embodied in some type of medium, such as paper or a computer. Because of their materiality, inscriptions are publicly and directly available, which implies that they are social objects with meaning potentials. A meaning, or a function, of any representation is not an inherent property, but arises from the context of its use (Säljö, 2005; Wertsch, 1998). Even though some of the representations we are introduced to in our everyday lives, or in educational or professional settings, are perceived as the normative way of displaying a concept, this does not mean that there is only one way of understanding or utilizing the representation. Neither do students necessarily employ the representations as intended by the designers or teachers. The meanings and functions of representations are (re)constructed in action. They can be used, invoked and referred to, or misunderstood, disregarded and ignored. This is to say that it is not possible to know or manage the ‘full’ meaning or potential of a representation—this would be unattainable. Instead, this is negotiable among interlocutors, and the function and understanding of a representation is always relative to a social practice (Schoultz, Säljö, & Wyndhamn, 2001).

The context-bound and practical way of approaching attainment of shared meaning and understanding does not mean that students can come up with any interpretation of scientific concepts or representations. In every scientific field, there is a range of terms, concepts and ways of talking about these terms and concepts that are accepted as valid. These valid ways of talking are what Lemke terms ‘thematic patterns’ (Lemke, 1990). Thematic patterns within a science field represent what we can regard as normative versions of scientific concepts. Likewise, within each expert domain, especially in mathematics and science, there are canonical representational forms (i.e., representations that have become the normative way of displaying and visualizing scientific concepts) (diSessa, 2004; Greeno & Hall, 1997). Models of solar panels, such as the ones with which the students in this study are interacting, are one example of a canonical way of representing a scientific concept. Becoming experienced within a particular knowledge domain often involves an interactive, successive shaping of the ability to single out the relevant elements of a representation. In other words, being able to make sense of representations involves a socially shaped way of ‘seeing’ (Goodwin, 1997).

Directing the analytical attention towards students’ conceptual sense-making means that the primary focus is on the interpretive work that needs to be undertaken in order to make sense of scientific concepts and how visual representations become structuring resources in such processes (Goodwin, 1997; Giddens, 1979; Lave, 1988). This implies seeing students’ interaction with representations as a particular practice embedded within an institutional setting with certain traditions of organising teaching and learning. Accordingly, by means of detailed interactional analyses, our analyses in this paper explore the interpretive work that the students undertake in order to make conceptual sense of solar panels, and how models of solar panels become structuring resources in the students’ sense-making processes.

**Research on students’ reasoning with representations**

Several studies have reported on students’ encounters with representations in computer-based settings and the implications for learning within science education. A vast majority of these studies are experimental or quasi-experimental studies focusing on the effect of representation employment on students’ acquisition of conceptual understanding and inquiry skills (Ainsworth, 2006). The effect is commonly measured by analysing students’ self-made representations and
their written explanations of scientific concepts, often in combination with various types of pre- and post-tests. Most often, the test situation involves settings where students work in solitude, implying that also the unit of analysis is individual students’ performances. Furthermore, the effects of representations on students’ performance are frequently explained by the specific properties of the representations, the combination of representations and/or students’ prior knowledge or skills (c.f., Ainsworth, 1999; 2006; van der Meij & de Jong, 2006; Seufert, 2003). One documented positive effect of students’ encounters with multiple representations is that representations can have a ‘complementary function’ in that they either differ in the type of processes each supports, or in the type of information they contain (c.f., Bodemer, Ploetzner, Feuerlein, & Spada, 2004). Representations can also have a ‘constraining function’, implying that certain combinations of representations can support students’ learning when one representation constrains the interpretation of a second representation. For instance, depictions can function as a specification of a textual description and thereby constrain how the students can interpret the text (Schnozt, 2002). A third potential function of multiple representations is as support in constructing ‘deeper understanding’, referring to the students’ capacity to abstract the underlying structure or principles of the represented concepts (Ainsworth, 2006; van der Meij & de Jong, 2006; Seufert, 2003). Despite the fair consensus of the positive effects of students’ employment with representations, challenging findings are also reported. Students often struggle to use representations effectively (Ainsworth, 2006; Bodemer et al., 2004; Kindfield, 1993/1994). For instance, in contrast to experts, students have difficulty moving across or connecting representations. Students also tend to focus on the surface features of representations, instead of the underlying scientific principles (Glaser & Chi, 1988; Kozma, 2003; Larkin & Simon, 1987).

As well as acknowledging the relevance of these studies and their input to design of learning environments, we argue that a more social- and process-oriented approach is needed in order to gain a deeper understanding of the function of representations in settings where students engage in collaborative computer-based learning activities. In collaborative learning settings, students are not making sense of scientific concepts and representations in solitude. In these settings, sense-making takes place via interactive and social activities where students discuss, negotiate and display their understanding both for others and themselves (Stahl, 2006). In his seminal study on face-to-face collaboration in a setting where students engaged with computer-based velocity and acceleration simulations, Roschelle (1996) turned the analytical focus towards the significance of representations in mediating collaborative inquiry. Through detailed analyses of student conversation and gestures, Roschelle shows how representations most of all serve as social resources for students’ meaning-making conversations, more than as a means for communicating expert knowledge.

There are few, but some, process-oriented studies combining a focus on the social and conceptual affordances of students’ employment of representations in collaborative learning settings (Suthers, & Hundhausen, 2003; White & Pea, 2011). These studies are, for instance, focused on representational tools aimed at supporting students’ scientific argumentation (Bell & Linn, 2000), distributed knowledge building (Ludvigsen & Mørch, 2003; Scardamalia & Bereiter, 1996) or concept-oriented talk between peers in classroom settings (Suthers & Hundhausen, 2003). The study by Suthers and Hundhausen (2003) shows that various visualizing tools can have different effects on student interaction and end products. By coding collaborating students’ utterances during their work process and the content in their written essays, the researchers found that student dyads using visualizing tools in the form of a graphing or matrix
tool elaborated more on the presented information than those working with a text-based tool. Furthermore, representations and discussions of evidential relationships were more frequent for dyads using the matrix tool, and users of the graphing version were most focused in their consideration of evidence during their discussions.

Other studies have shown positive implications of students’ self constructed representations in collaborative settings. For instance, Schwartz (1995) found that representations made by dyads outperformed representations made by individual students in settings where students solved reasoning tasks related to physics and biology. In order to facilitate discourse, dyads needed to negotiate a common representation that could be used as a shared reference for coordinating their different views on the presented problem. By acting as resources for consolidating different views on a problem, the representations tended to become abstractions of the problem at hand. Positive implications of students’ self-constructed representations are also demonstrated. For instance, a study by Kozma (2003) focuses on how student-constructed computer-based molecule models supported conceptually oriented talk among collaborating students, and among students and teachers. Constructing and interacting with the models became important resources for the students in order to discuss and reflect on corresponding chemical concepts. Furthermore, the analyses showed that student talk was significantly more conceptually oriented in computer-modelling sessions than lab experiment settings where the students did their actual chemical synthesis. The increase in conceptually oriented talk during the modelling sessions also characterized the teacher-student interactions.

A final work of interest for the study reported here is a design study performed by White and Pea (2011) focusing on middle school students’ engagement with distributed multiple representations presented to them on handheld computers. By following groups of collaborating students over time, the changing character of student interaction as it proceeded, as well as changes in the students’ use of the representations, were demonstrated. Working on the topic of mathematical functions in small groups, the students were introduced to multiple representations such as graphs, function tables and frequency tables in order to make and break codes. First, the study demonstrates how the students capitalized on the various representations in order to find solutions to the presented problems. Analyses of student interactions during the problem solving processes show that the students successively attuned towards, and coordinated, their individual views of different code representations. Furthermore, the students gradually became capable of using and supplementing representations enabling them to solve complex functions, as well as becoming capable of communicating with mathematical precision.

It is important to emphasize that, despite the positive findings in the presented studies, more challenging aspects of students’ engagement with representations in collaborative settings have also been reported. Further, in collaborative settings, students tend to experience difficulties with moving across and connecting multiple representations (White & Pea, 2011). Students also tend to focus on the surface features of representations instead of the underlying scientific principles (Krange & Ludvigsen, 2008). As documented, for instance, in Kozma’s study (2003),
students often find it hard to transfer experiences from one setting to another. Furthermore, several studies show the considerable coordination of effort needed from each participant in order to attain collective interpretations and effective alignments within the collaborating peer group (Furberg & Arnseth, 2009). Analyses of small group interactions also show the risk of collaboration breakdowns in small group interactions; on the one hand, students capitalize on using the representations moving toward increasing accuracy and efficiency, but this sometimes occurs at the expense of participation from all the members in the student group (White & Pea, 2011).

In the following section, we account for our analytical and methodological approaches to exploring aspects of students’ use of representations in computer-based collaborative settings.

**Research design**

**Setting and participants**

The empirical data were produced during a school project about energy and heat transfer in March 2010. The project was carried out in 20 school lessons over the course of four weeks. The participants were 20 upper secondary school students, aged 16 to 17 years, and two science teachers. Ninety students volunteered to participate in the project, of which 20 were randomly selected to participate, with their selection only correlated according to gender balance. According to the teachers, the students can be classified as average to high-level achievers in science. The central resource for introducing students to the energy and heat transfer curriculum was the computer-based learning environment SCY-Lab, which contains visual and textual representations such as graphical representations, diagrams and simulation tools, supplemented with information from the Web and textbooks. At the centre of the students’ work in the project was designing a sketch of a CO2-friendly house. The students worked in groups of four, preparing for and carrying out a plenum classroom debate related to the choices they made during the process of designing their houses. During this group activity, the teacher circulated among the groups in order to support their discussions and help the students organize their work.

The organization of the educational setting was based on a jigsaw model, implying that students alternated between two types of work groups: expert groups and basic groups (Aronson et al., 1978; Brown, et al., 1993). At the beginning of the project, the students were organized into four expert groups containing one student from each of the basic groups. Each of the four groups was given one of four designated expert fields to focus on: solar cells, heat pumps, energy laws and sources or energy use. The expert group task implied that the students were to retrieve information related to their topic by means of various information sources like the Web, textbooks, and SCY-Lab. The intention was that the students would feed in and re-use information and experiences from the expert group setting in their basic group setting, where they were to design their house as a joint effort. Furthermore, the intention was that the jigsaw model would ensure that all students received input from all four designated expert fields.

**Data and analysis**

The main data material in this study constitutes 60 hours of transcribed video recordings of three selected student dyads’ interaction while engaging to design a CO2-friendly house in the context of the computer environment SCY-Lab. Additionally, notes taken during classroom
observations represent important supplementary contextual data for the analyses of the students’ interactions. The initial analysis of classroom observations and students’ end products showed that all participating student groups showed an extensive use of representations, both during their project work and in their final presentations of their group tasks. The preliminary analyses of the interaction data produced in the three focus groups made it possible to identify what can be seen as a general practice of how the students engaged with various types of visual representations during the project.

In order to explore and understand how students encounter representations while participating in conceptual sense-making in collaborative settings, we have been concerned with examining the students’ ‘accounts’, where accounts are seen as specific forms of language use, actions such as explanations, clarifications or justifications (Scott & Lyman 1968; Mäkitalo 2003). By focusing on students’ accounts, the attention is on the students’ concerns—what they treat as relevant—and how they try to deal with conceptual sense-making in their talk. Furthermore, we emphasise the importance of seeing students’ sense-making as an evolving and changing process taking place not only through moment-to-moment interactions, but also across longer stretches of time (Engle & Conant, 2002). A focus on what is termed students’ ‘interaction trajectories’ makes it possible to study how students’ orientations change over time (Ludvigsen et al., 2011; Furberg & Arnseth, 2009). A focus on students’ talk and interactions during their interaction trajectory then directs a focus on the discursive relationship between episodes (Linell, 1998) taking place within a period of time—or an activity-limited educational setting, as well as being sensitive to changes in participants’ orientations during the course of time. On a theoretical level, the concept of interaction trajectory is important because it provides for the possibility of exploring the interpretations students undertake in order to make sense of scientific concepts and how representations become resources in several ways in different situations over time. In talk and interaction, topics and themes are discussed, negotiated and possibly left behind, only to be reintroduced later. Following students’ activities over time might enable us to see how thematic patterns unfold (Engle & Conant, 2002). Most important, however, is that a focus on students’ interaction trajectories makes it possible to identify how students’ employment and understanding of representations are embedded in, and interdependent with, complex social and cultural contexts (Säljö, 2005; Wertsch, 1998). In this paper, four extracts from one student group’s interaction trajectory taking place within the setting of a project about energy and heat emission are selected and analysed in detail. At the core of the students’ discussions is the function of solar panels. By analysing selected chronological extracts of the students’ interaction trajectory, we are able to see the changing role of the solar panel models and the evolving process of students’ sense-making of the visualised physical principles of solar panels.

In addition to a detailed examination of specific extracts of interaction, ethnographic information about the institutional setting has been used as a background resource for understanding what was going on. The selection of data for in-depth analysis was also selected in relation to our research questions. We have chosen to present data that gives rich insight into how these types of talk and interaction are intertwined with the specific representation that becomes activated and used by the students (Jordan & Henderson, 1995; Derry et al., 2010). The students’ discourse took place in Norwegian, and the researchers made the translations.

In qualitative studies like this, the question about reliability is concerned with how well we capture the phenomena that we investigate. The selected data give us very rich information about both teacher-student interaction and student-student interaction in terms of their use of the
representations. The internal validity is secured through the ‘steps’ in the analytic procedure, from the first screening of the collected data, through the transcription of the data, to the detailed analysis and representation of the data in the article. The generalizations that we make are within the data corpus, which means that, based on the data analyses, we can argue that we have identified general patterns in the social practice. These findings will be discussed in relation to the findings presented in the review section. Together with the findings in this particular study, we create a set of the analytic generalizations.

Results

In the following, we scrutinize four extracts from a student group’s interaction while working on a project about energy friendly houses. The two first extracts are selected from a teacher intervention setting and take place in an expert group session early in the project trajectory (Extract 1 a b). Here, we meet the three students, Ann, Sue and Linda, in discussion with the teacher about the function of solar panels. In this extract, the teacher tries to explain the basic elements of the solar panel function. Extract 2 is also selected from the same expert group setting and takes place only minutes after the teacher left the students. In this setting, we see how the students employ and try to make sense of the teacher’s explanation when they are about to write down their own explanation of solar panels to her basic group peers. Extract 3 occurs after the expert group students have gone back to their basic groups to explain to the other students the specific concepts they have been working with in the expert group. In this setting, we focus on a sequence where Linda, one of the three girls in the solar panel expert group, tries to explain the function of solar panels. By following the students’ talk over time, it will be possible to see how and why the representations in use play an important role in the students’ sense-making.

Setting 1: Reasoning with representations in teacher intervention settings

The following two extracts are selected from a teacher intervention setting. As in most educational settings, the teacher represents an important learning resource when introducing students to normative versions of scientific concepts. In this project, the teacher alternated between giving short plenum lectures and circulating among the groups in the classroom, approaching those who asked for help. The following interaction takes place early in the project. The students have just started their work in the expert groups. Most of the groups have already found a lot of information about their designated topic, either within the SCY-Lab, on the Web or by using their textbooks. In the following two extracts, we follow three students, Linda, Ann and Sue. Their expert group has been given the task of retrieving information about and explaining solar panels as a potential heat source in private homes. Linda, Ann and Sue have summoned the teacher and asked him to explain to them the function of the solar panel, a concept they find hard to understand. The teacher starts to go through the functions step by step, from A-Z. During his explanation, the teacher makes explicit references to a model of the solar panel process depicted in the students’ textbook. A reconstruction of the model is shown in Figure 1.
We enter the episode when the teacher is about to sum up the main points of his explanation. 

*Extract 1a):* 

1. **Teacher:** We have to think about the membrane as a downhill slope [looks at the students, and the students nod in the affirmative]. What happens in a downhill slope - - um, what happens here then [points to the n-plate in the figure], is that the surplus of the electrons here, they will wander from the n-type to the [2] p-type. Then you can imagine the barrier, the membrane, as a downhill slope [gesticulates with his arm]. It can only roll one way; it won’t roll back. Can you imagine that? 

2. **Students:** Nodding 

3. **Teacher:** And then it will find, and open up, the hole at the back. 

   [...] 

4. **Teacher:** In the nucleus here - [pointing to the n-plate in the solar panel model in the textbook] because in phosphorus you’ll find three protons. And then, one extra electron has entered in here, like this [indicating the electron moving from the p-plate to the n-plate]. So, here you have a case with three protons and four electrons. Do you agree that it ends up being surplus of negative charge? 

5. **Students:** Nodding 

6. **Teacher:** And this is what happens here, right? Likewise, here, where you see the silicon. Here, one must have a surplus of positive charge [pointing to the n-plate]. The electron, there [points to the n-plate in the solar panel model], has moved over to the free holes on the boron side [indicating the electric circuit]. There, we’ve got 15 protons in the nucleus, but only 14 electrons around it [pointing to the p-plate]. 

7. **Students:** Nodding 

8. **Teacher:** Then, we’ve got surplus of- [Looks at the students awaiting their reply]. 

9. **Linda:** Positive 

10. **Ann:** Positive, yes. 

11. **Teacher:** Were you with me? Did you understand it now? 

12. **Sue:** Yes. Okay.
In this extract, the teacher starts to recap and sum up the essential parts of his earlier walk-through of the solar panel’s function. While explaining, the teacher uses a model depicted in the students’ textbook (see Fig. 1). By pointing at specific elements in the depiction, as well as gesticulating the movements of the electrons, the teacher offers a detailed and complex explanation of how the surplus of negative charge on the n-plate (phosphorus doped silicon) causes the electrons to move over to the p-plate (boron doped silicon) through the electric circuit. An interesting aspect of this extract is that it demonstrates what we can term a typical form of classroom discourse in a teacher intervention setting. The conversation between the participants is, first and foremost, characterized by the teacher providing lengthy utterances in the form of explanations about scientific concepts that, in this case, relate to the solar panel function. The students, on the other hand, follow up with short and, most of all, confirmative utterances. By studying the students’ gazes, it is obvious that they pay close attention every time the teacher points to the elements in the solar panel model. By studying the extract more closely, it is also possible to see how the teacher, in different ways, tries to invite the students into the conversation by using verbal pauses (line 3), asking questions (lines 1 and 4) and serving uncompleted sentences (line 8). The teacher’s invitations seem to prompt two types of responses by the students. First, the students respond with utterances indicating understanding, such as nodding and short confirmative expressions. They also respond by completing the teacher’s uncompleted sentences (lines 9 and 10). Second, the teacher’s invitations give the students a chance to explicate if there is something about his explanation that they do not understand. As we see, this is what Ann does in line 13, below. Extract 1b) is a direct continuation of Extract 1a) above:

**Extract 1b):**

<table>
<thead>
<tr>
<th>Line</th>
<th>Speaker</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td>Ann</td>
<td>But, I don’t understand, because they say that the sunbeams hit the p-plate [points at the p-plate].</td>
</tr>
<tr>
<td>14.</td>
<td>Teacher</td>
<td>Yes, but you should think about what’s typical for the p-plate, here [points to the p-plate in the textbook model] (.).</td>
</tr>
<tr>
<td>15.</td>
<td>Ann</td>
<td>Uh huh?</td>
</tr>
<tr>
<td>16.</td>
<td>Teacher</td>
<td>On the silicon, there is surplus of electrons.</td>
</tr>
<tr>
<td>17.</td>
<td>Ann</td>
<td>Oh, so they hit the electrons and then they shoot-</td>
</tr>
<tr>
<td>18.</td>
<td>Teacher</td>
<td>Yes, yes. They must hit the electrons (.). And you must remember that boron, which is doped there- When the electrons have moved from silicon over to boron, the boron has three protons in the nucleus, but four electrons around (.).</td>
</tr>
<tr>
<td>19.</td>
<td>Ann</td>
<td>Um. Okay</td>
</tr>
<tr>
<td>20.</td>
<td>Teacher</td>
<td>[pointing to the n-plate] This is why it got a surplus of electrons. So, when it is bombarded with sunlight, it will get a photovoltaic effect [indicating the p-plate]. Then that electron is hit like this, those in surplus, and then they will move. And move [pointing to the electric circuit] in the electric circuit over to this side.</td>
</tr>
<tr>
<td>22.</td>
<td>Teacher</td>
<td>And it will move continuously (.).</td>
</tr>
<tr>
<td>24.</td>
<td>Linda</td>
<td>Yes, okay.</td>
</tr>
<tr>
<td>25.</td>
<td>Teacher</td>
<td>So, that was the most complicated point, there from the n-type to the p-type. But you have to think of the relationship between the number of protons in the nucleus</td>
</tr>
</tbody>
</table>
and the electrons around it.

27. Teacher: Now, did you get it?
28. Students: Yes

[The teacher leaves the students and approaches another group].

In the opening of the extract, Ann says that she does not understand the relationship between the sunbeams hitting the solar panel and the electrons’ movement from the p-plate to the n-plate. The teacher responds to Ann’s query by explaining that particular part of the process once again. As in Extract 1b), the conversation between the participants is characterised by the teacher providing lengthy utterances in the form of explanations and the students following up with short and confirmative utterances. Furthermore, the teacher continues referring to the solar panel model in order to illustrate elements in his explanation. When he has finished his explanation, the teacher asks the students if they understand it now (line 27), and all the students reply with a “yes” (line 28). As we see, the teacher seemingly takes the students’ “yes” as a token of understanding, or at least as an indication that the students can carry on with their work by themselves. He leaves the students and approaches another group.

The two extracts above clearly illustrate the central role of representations in settings where complex scientific concepts and processes are to be explained. In the extracts above, two types of representations are in play. The first representation in use is the downhill metaphor the teacher uses in order to describe the function of the membrane separating the n- and the p-plates in the solar panel. As we will see later in the students’ interaction trajectory, this metaphor will be used and referred to in another setting, when Linda tries to explain to the students in her basic group what they found out during their expert group work. By introducing this symbolic but experience-relevant metaphor, the teacher provides a useful resource that the students can employ when they, in other settings, reconstruct and talk about the complex processes taking place in a solar panel.

Another central representation in this extract is the textbook model depicting the solar panel’s function. In fact, the main part of the teacher’s explanation about the moving electrons in a solar panel is difficult to understand in terms of the spoken language alone because much of what is said has essential visual referents in the textbook model. This way, the verbal and the visual representations become intertwined and are inseparably connected. In the process of introducing the students to the photovoltaic process in solar panels, the teacher links each step of the process to the depicted details in the solar panel model. The link is made explicit by physical gestures and verbal referencing of the solar panel model. Said differently, he makes an explicit link between his verbal utterances and the details in the visual representation. This way, the representation becomes a shared reference point and a resource for the teacher during his explanation. Furthermore, the extract shows how the representation becomes an important resource for the students when posing queries to the teacher. This can be exemplified by Ann’s query in line 13, where she says, “I don’t understand, because they say that the sunbeams hit the p-plate”. The direction of Ann’s query is difficult to understand in terms of the spoken language alone. However, the fact that Ann simultaneously refers to the p-plate in the model gives information on what part of the process she finds problematic. As we see in lines 14 and 18, the teacher responds by accounting for the relationship between the sunbeams hitting the solar panel and the electrons’ movement from the p-plate to the n-plate.

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It is important to emphasise that students’ confirmative expressions during teacher intervention sessions must not be seen as a reflection of their genuine understanding. Instead, such expressions should rather be seen as linguistic devices that enable the teacher to go on in his explanations. As we will see during the next extract, the students still struggle with constructing an understanding about certain elements of the solar panel’s function.

**Setting 2: Reconstructing the normative version presented by the teacher**

We enter the following setting some minutes after the teacher has left the students. After the teacher left, the students immediately started to write up a short explanation of the function of a solar panel. They write their text in a program called OneNote. While writing, the students confer with the text about solar panels and the model (see Figure 1) depicting a solar panel in their science textbook. While conferring with the others, and reading what she writes aloud, Linda types in their description into OneNote. The text frame in Figure 2 represents their description of the function of a solar panel:

![How a solar panel works.](image)

**Fig. 2: The explanation the students documented in OneNote of the function of the solar panels.**

Just before the opening of the following extract, the students have finished writing their explanation in OneNote. Linda suggests that they find an image to accompany their text about the solar panel’s function. Sue and Linda start browsing Google for images, each of them using their own PC. In the opening of this extract, we see that Sue finds an image that she suggests they use. It turns out that this model (see Figure 3) becomes central to the students’ work throughout the remainder of the project.
It is worth noting a slight difference between the solar panel representation in the students’ textbook and the representation they found on the Internet. If we look closer at the representation found by using Google (Figure 3), we see that this model depicts sunbeams hitting the n-plate in the solar panel. The textbook representation, however (see Figure 1), depicts sunbeams (=photon) represented by means of the wavy arrows passing through the n-plate and the barrier reaching the lower p-plate. As we will see, the differences between the two representations play a central role in the following sequence. We enter the episode when Sue finds an image that they can use:

**Extract 2:**

1. Sue: We can take this one, here.  
   [Turning to her computer screen in order to show a model to Linda and Ann, she points at the model. (See Figure 3)]  
   Here it comes on the n- [indicating the sunbeams hitting the n-plate] (3). I don’t get it.

2. Sue: [Looking at the model she found in Google] If the sun hits the n-plate, then how can--? [Reads to herself in a low voice.]

3. Ann: You mustn’t confuse me now.

4. Sue: But, I thought that it was like this [referring to the p-plate in the Google model] (.), But obviously it’s not. But if—I sort of thought that the sunbeams come like this, and like they--

5. Linda: But, isn’t that one right in a way? [Pointing towards the Google model.]

6. Sue: Yes.

7. Ann: Yes, because it is perhaps like this then, because then it only has to overflow--

8. Sue: But it’s something here as well [pointing to the model in their textbooks. (See Figure 1)]. They come like this [indicating the sunbeams], and then it passes through [pointing to the membrane separating the n- and p-plate], and then it hits this one, like
In the opening lines of the extract, Sue and Linda agree that they have managed to give a reasonable explanation of the functionality of solar panels. Linda suggests that they should find a model as a supplement to their explanation. Linda starts browsing Google, looking for models to use. They settle for a simple model, which they copy and paste into their working area. Their conversation takes an interesting turn when Sue starts to study the model they found with Google. While looking at the model, Sue starts to question her conception of where the sunbeams hit the solar panel (line 3). Ann chides Sue not to confuse her now, indicating that her fragile understanding easily can be destroyed. All the same, Sue refuses to let go of what she finds problematic to understand. She explains that she thought that the sunbeams hit the p-plate, and not the n-plate as the model indicates. Her utterance, ‘I thought that it was like this, but obviously it’s not’ (line 5) indicates that she has more confidence in how the model depicts it than her own conception. Linda agrees that the model is probably representing it correctly. Sue finds the model of the solar panel function in their textbook and starts to compare the two models. By talking her way through how the sunbeams hit the solar panel while pointing to the relevant details in the solar panel model, Sue manages to verbalize that the sunbeams affect the electrons both on the n-plate and the p-plate. Then, Sue and Ann turn their attention to the caption accompanying the solar panel model in the textbook. After some individual reading Sue says, ‘Ah. So they come on the n’. By using the expression ‘Ah’, she signals that “now I understand”. Ann responds by signalling that she, too, has come to a new understanding (line 12). She continues by elaborating to say that the sunbeams “pass through” the barrier separating the n- and the p-plate in the solar panel. Sue confirms Ann’s elaboration by adding ‘because it is only the electrons that do not pass through [the barrier]’. After this sequence, the students continue writing text in OneNote on another solar panel-related topic. They leave their solar panel text (see Figure 2) as it was before they talked their way through the solar panel’s function.

One of the most striking things about the previous extract is that it clearly demonstrates the intertwined relationship between the students’ talk and the visual representation of the solar panel’s function. As with Extracts 1 a) and b), the main part of this episode is difficult to understand in terms of the spoken language alone because much of what is said has essential visual referents. By linking the students’ utterances and their verbal and physical references to the details in the solar panel model, it is possible to see that the students are capable of participating in reasoning about a complex scientific concept. So, more specifically, what type of work do the representations do for the students in this setting?
First, it is possible to say that the representations become resources that enable the students to address and discuss small, but essential, details within an expert field without necessarily being able to express all elements of their reasoning verbally. Hence, the representations become resources in two different ways. First, the visual features of the representations both enable the students to articulate what they find hard to understand, and yet also allow them to articulate their own assumptions about the elements of the photovoltaic process that takes place within solar panels. In other words, the use of the representations enables the whole group to participate in joint reasoning about how to understand the scientific concepts at issue.

The second interesting aspect of the interaction in Extract 2 concerns the issue of multiple representations. In this extract, there are several representations in play: the text in the students’ textbook and the two different models of the solar panels. Furthermore, despite the fact that the students do not directly address the teacher’s explanation in this extract, we can assume that his explanation functions as a backdrop for the students as well. As discussed above, Sue expresses that there is a tension between her initial understanding of where the sunbeams hit a solar panel and how the model found using Google depicts it. In order to sort out the confusion, the students turn to the model in their textbook. A second confusion then occurs, this time caused by the fact that the two models depict the details of sunbeams hitting the solar panel in slightly different ways. In order to solve the confusion, the students check the caption of the solar panel model in their textbook. Then, they seemingly land on a shared understanding of that particular part of the process. In other words, by using elements from three representations, the students manage to construct a valid explanation of the photovoltaic process within solar panels. In a sense, it is possible to say that both Sue’s expressed confusion about where sunbeams hit the solar panel caused by one of the solar panel models, as well as the differences between the two model representations, constitute productive driving forces in the students’ process of constructing conceptual understanding. The difference between the two models makes it necessary for the students to dig deeper into the phenomena in order to construct a shared understanding. In other words, the analysis shows how the students use the multiple representations in their process of constructing conceptual understanding. The representations enable the students to negotiate and reconstruct the normative version of the scientific issue presented to them by the teacher.

The three extracts analysed above are selected from the phase during which the students were working in their expert groups. Despite the fact that students have the same access to the teacher and a variation of visual and textual representations as important sources of information, we have seen that it is no trivial matter working to construct a shared conceptual understanding of the scientific concepts at issue. So, what happens when the students leave their expert groups in order to explain to the other students in their basic group about the concepts with which they have been working? This is what the next extract will demonstrate. Here, we will focus on an interaction sequence from the setting where Linda is to pass on the expert group’s explanation of solar panels to her basic group peers.

Setting 3: Explaining to peers; Re-constructing the re-constructed version of solar panels

Along with her peers, Linda has just returned from her expert group. The students have been instructed to present their field of expertise to the others. Each student is given approximately 15 minutes for his or her presentation. The students sit in groups around a table in the classroom, each with his or her own PC in front of them. In the following sequence, Linda is in the middle of her presentation on solar panels. We enter the students’ conversation at a point
where Linda gives a summary of the expert group’s explanation of the electrons’ movement from the n-plate to the p-plate.

 Extract 3:

1. Linda: Yes, um, and then it is negative loaded. And both these plates have another substance added, and that is kind of called that the plates are “doped”. Because they lack or have too many electrons [looks at her screen while explaining, but looks occasionally at Claire] (2) Did you get that first part?

2. Claire: I didn’t understand it completely. Sorry

3. Linda: Okay, um… Yes, uh, uh, uh um. You can have this afterwards [points at her OneNote notes]. It might be easier - I am not that good at explaining, but-

4. Claire: Oh yes, you are [looks at Linda].

5. Linda: Um, like how does a solar panel work in a way. I do not understand it completely, but I can try. Um, in a way, you can say that - [gesticulating by putting her hands on top of each other] there are n-types, or that the n-type silicon plate is this one, and this one is the p-type silicon plate. Then, there is sort of a battery, or sort of like a slide, as the teacher called it, between - It is very hard to show if one doesn’t understand it, but - The sunbeams hit the solar panel and kick the electrons over from the n-plate to the p-plate. Do you know what I mean?

6. Rachel: Yes.

7. Linda: Because it goes downhill in a way - the slide you know, and the electron wants to get back, um, back to the p-plate. But because of that barrier, it was a slide you know, it can’t go upwards.


9. Linda: Um, and then the electrons need to go through an external circuit, and, like, it is then the circuit makes something glow and therefore it gets light, or - electricity. Um, if you understood some of it?

10. Rachel: Yes, I think I understood it.

11. Claire: [Looks at the solar panel model that the expert group found on the Internet on Linda’s screen] Oh yes. Like with an El-car you know.

12. Linda: Nods

13. Claire: Yes, okay. Then I understood.

14. Linda: [Turns her screen so that all three can see] This is like a drawing. The solar cells go through, or they get kicked down there [pointing to the electrons moving from the p-plate to the n-plate], but they want, in a way, to go back again. They slide down here [motioning to electrons moving from the p-plate to the n-plate].

15. Claire: They go down into the blue [pointing to the electrons moving from the p-plate to the n-plate].

16. Linda: Yes, so they - they go into the blue, and they want to go there [showing a movement from the n-plate to the p-plate through the separating membrane], but they have to go through here in a way [referring to the electrical circuit].

17. Claire: But is it only electrons that go through here [indicating the electrical circuit], and then the rest goes in a way? [points at Linda’s screen]

18. Linda: No, the rest stays here in a way [points at the screen].

At the beginning of the extract, Linda sums up the expert group’s explanation of the electrons’ movement from the n-plate to the p-plate. While explaining, she looks at the notes made by the expert group earlier. Midway she pauses and asks the others if they have understood her explanation. Claire responds by saying that she does not understand “completely” (line 2). Linda offers her notes to Claire and says that she probably will understand more just by reading the expert group explanation herself, and excuses herself by saying “I am not that good at explaining”. Claire encourages her to go on with her explanation by assuring Linda that there is nothing wrong with her explanation skills. Linda gives it another go. This time, Linda does not read from her notes. Instead, she uses the downhill metaphor that the teacher introduced (see Extract 1a, line 1) when he explained the function of the membrane in the solar panel. This time, both Rachel and Claire respond that they think they understand Linda’s explanation (lines 10 and 13). An interesting turn in the conversation takes place when Claire notices the solar panel model that the expert group found on the Internet (Figure 3). Linda turns her computer so that all of them can see the model. Then, she starts to go through the explanation one more time, this time pointing to the relevant places in the model, along with the detailed explanation of the photovoltaic effect (lines 14, 16, 18 and 20). Claire follows up Linda’s explanation by asking clarifying questions along the way (lines 15 and 17) and by responding with affirmative confirmations indicating that she follows and understands Linda’s explanation (lines 19 and 21).

The extract presented above shows that the students find it hard to understand Linda’s first attempt at explaining a solar panel’s function. Furthermore, it shows how hard it is for Linda to come up with an explanation that makes sense for the others in her group. The most interesting aspect, however, is that the extract demonstrates the essential role representations can have in settings where students construct explanations of scientific concepts. During the students’ interactions taking place during this sequence, two representations are in play. The first representation in play is the downhill metaphor of the function of the membrane provided by the teacher (see Extract 1a, line 1). By introducing this metaphor, Linda manages to elaborate on and deepen her explanation of the scientific photovoltaic effect. As we see, both Claire and Rachel respond by saying that they “think” they understand a bit more. However, the most powerful resource seems to be the solar panel model depicting the underlying physical principles of solar panels. When Linda introduces the model, we see that the situation turns. As we saw in the analysis of Extract 2, the solar panel representations are turned into a shared focus point between the students, enabling them to provide and receive clarifying questions, comments and corrections.

Discussion and concluding remarks

We opened this paper by posing two guiding questions central to our search for a deeper understanding of how representations become structuring resources in students’ collaborative learning processes: How do collaborating students engage with representations presented to them in the computer-base inquiry learning environment, and in what ways are the representations functioning as structuring resources in the students’ evolving process of conceptual sense-making? In order to discuss these guiding questions, we have performed detailed analyses of
students’ encounters with representations during their interactions taking place within the frame of a science project about energy and heat transfer. The analyses of the participants’ interaction display three important issues on which we will elaborate.

The first issue concerns how the solar panel model becomes a central conceptual and social resource in the teacher intervention setting. The analyses of the participants’ interaction in *Extracts 1 a) and b)* display what can be seen as a well-known interactional pattern in teacher-student interaction: The teacher presents a detailed explanation about a scientific concept and prompts student participation by asking consensus- and fact-oriented questions, serving unfinished sentences and making pauses between his utterances, leaving room for the students to enter the conversation (Lemke, 1990; Mortimer & Scott, 2003; Wells, 1999). The concept of solar panels and the photovoltaic effect is complex and dense, and consequently making sense of, as well as explaining these concepts, is not a trivial matter for students and teachers. The most interesting aspect of the teacher intervention setting is that the analysis demonstrates how, in different ways, the solar panel representation becomes a conceptual resource in the participants’ sense-making, first, as an important resource for the teacher when providing his explanation to the students. By pointing out details in the model, the teacher manages to construct a rich and detailed explanation of the photovoltaic effect by combining verbal and visual explanations. Second, the model becomes a conceptual resource for the students: by examining specific elements in the model, they are capable of using precise and scientific terms in their sense-making of the photovoltaic effect. Their reference and direct referral to the representation also enables the students to put forward precise and detailed questions to the teacher about the issues they find hard to understand.

The second issue we would like to highlight is how the representations become important conceptual and social resources in collaborative sense-making between peers. The analysis of *Extract 2* shows what takes place after the teacher has left the students. As we have seen, constructing relevant frames for understanding the task, explanations of concepts and developing their conceptual understanding is cognitively and socially demanding for the students, even though they receive relevant guidance from their teacher. Even though the teacher provided the students with an excellent and detailed explanation of the photovoltaic effect, and the students confirmed their understanding of it when asked by the teacher, the analysis of *Extract 2* demonstrates that the students still had a fragmented understanding of the function of solar panels. When finding a second solar panel model on the Internet depicting the same phenomena in a slightly different way than the textbook model, the students suddenly become unsure of their own understanding. By addressing the differences in the two models’ ways of representing the photovoltaic effect, and by reading the caption, the students manage to formulate their own explanation and clarify an unsolved misunderstanding collaboratively. Put differently, the differences in the two models made it necessary for the students to solve what, to them, appeared to be a ‘dissonance’ between the teacher’s explanation, their own comprehensions and the two solar panel models. This dissonance is resolved when they go through the two models step by step and compare the differences between the models as they read the model caption in their textbook. Together, and by examining the elements in the models, the students solve their misunderstanding and become capable of formulating their own explanation of solar panels.

The analysis of *Extract 3* shows another example of how representations become important resources in peer interaction. This particular project was organized according to the jigsaw model. The basic idea of the jigsaw model is to create ‘asymmetry’ between the students by means of their participation in designated expert groups. Potentially, the asymmetry will
create possibilities for the ‘expert students’ to elaborate and try to create explanations that the other students can understand, and create possibilities for novice peers to pose questions and ask for further elaboration (Aronson et al., 1978; Brown et al., 1993). The analyses of the students’ interaction in Extract 3 illustrate the complexity of settings where a more experienced student is to explain to less experienced students about dense scientific concepts. In this setting, Linda is back with her basic group and explaining to them about the function of solar panels. As the analysis of the students’ interaction shows, Linda finds it hard to come up with a satisfying explanation, and the other students signal that they do not understand her explanation. However, as described, the interaction between the students changes when Linda shows them the model representing the solar panel’s function. By pointing out the specific elements in the model, Linda becomes capable of re-constructing a detailed explanation of the solar panel model. Furthermore, the less experienced peers are able to ask her precise questions, and can get confirmation from Linda that they now understand the elements in the process. Based on this, it is possible to say that the analyses of the two peer settings clearly demonstrate how the representations become important resources in the settings where conceptual explanations ‘travel’ from one setting to another or – put differently – it shows the potential of representations for transferring experiences made in one setting into a new setting.

The third issue we would like to highlight is that the study echoes the findings from other studies showing the considerable interpretive effort that students need to undertake in order to make sense of scientific concepts, as well as representations to which they are introduced (Furberg & Arnseth, 2009; White & Pea, 2011). Nevertheless, the study also confirms some of the common challenges found in other studies. One frequent finding is that students often find it difficult to move across or connect representations. Such translation difficulties are assumed to be one of the main factors impairing students’ learning outcomes (Ainsworth, 2006; Kozma, 2003; van der Meij, 2006). Our analyses of the students’ interaction trajectories also reveal that students, to some extent, found it hard to connect the two slightly different versions of a solar panel, as seen in Extract 2. However, we argue that being exposed to differences in representations or various representational forms might prompt students to participate in exploration, justifications and negotiations of how to make sense of scientific concepts as well as the representations themselves. For instance, as shown in the analysis, the differences in the two models make the students take another round explaining the physics principles of solar panels, and thereby clear up a shared misunderstanding. In settings where students are working alone with different representations and few supplementing resources, it is understandable that students might find it harder to see the relationship between the representations. In collaborative settings, however, different representations, combined with the possibility to discuss them with peers, teachers, and use supplementary learning resources, are an opportunity for productive sense-making processes (Furberg & Arnseth, 2009; White & Pea, 2011). This implies that, instead of seeing the interpretive effort and the time needed for doing this as a pedagogical challenge, students’ interpretive effort can be regarded as the very core of their conceptual sense-making. Based on findings from process-oriented studies of students’ engagement with representations, it possible to assert that the documented difficulties seen in some individually oriented studies might not only be related to the properties of the utilized representations. The difficulties can also be seen as related to the fact that the students in these test situations are working in solitude with no possibility of discussing concepts with peers, teachers or the use of supplementary learning resources.
Another frequent finding in both individually oriented studies and collaboration oriented studies is that students often tend to focus on surface features of representations instead of their underlying scientific principles (Glaser & Chi, 1988; Kozma, 2003; Krange & Ludvigsen, 2008). The analyses of the students’ interaction trajectories make it possible to claim that the students in this setting move far beyond focusing on the surface features of the representations. Furthermore, it is possible to argue that the students, through their interaction with the teacher, their peers and the representations, participate in complex and valid sense-making, implying exploration, argumentation and justification for their own and others’ understanding. Without over-generalizing the activities taking place in the group analyzed above, it is possible to argue that the premises for students’ learning with representations are different in collaborative settings than in settings where they are working alone. Again, it is possible to see how interaction with peers and representations constitute potential opportunities for sense-making.

Another important aspect is the significance of teacher intervention. An interesting aspect of the analyses of the students’ interaction trajectory is that the analyses clearly show the importance of detailed and guiding explanations provided by a teacher in order for the students to be able to construct their own account of scientific concepts, as well as being able to grasp the representations’ underlying conceptual principles. The teacher’s explanation gives epistemic direction for the students and points out how they can use the representation for developing their conceptual understanding beyond the surface features of the representations.

In this paper, we have stressed two analytical points that, according to a socio-cultural perspective on students’ learning processes, are essential in order to understand the process of students’ conceptual sense making. The first point refers to the importance of approaching representations as structuring resources in collaborative settings. This entails a focus on how representations are referred to, (mis)understood and included in students’ interactive sense-making. Furthermore, such a focus does not exclusively focus on the properties of the representations in themselves, but rather on how the meaning potential of the representations is realized within and during social interactions between participants in the educational setting. The second emphasis is on the evolving character of students’ conceptual sense-making. In the analysis, we have scrutinized three settings selected from the students’ interaction trajectories. Each of these settings occurs frequently in inquiry-oriented learning activities. Focusing on students’ interaction trajectories makes it possible to see how their sense-making changes over time, within and between settings, and how different elements intertwine with their sense-making. By approaching representations as structuring discursive resources in collaborative learning settings, we have demonstrated how the students’ conceptual understanding becomes constructed in the intersection between teacher instruction, interaction between peers and features of the representations at hand. The study of collaborative processes enriches the scientific understanding of how and why interacting with representations under specific conditions leads to students advancing their conceptual understanding. If we do not understand these processes, it becomes difficult to answer questions about how specific representations mediated through computer-based environments can stimulate and enhance students’ conceptual sense-making in collaborative learning settings.

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**Notes**

i For a more detailed description of Science Created by You project and SCY-Lab see de Jong et al., 2010.

ii Transcript notations:

- [ ] Text in square brackets represents clarifying information
- = Indicates the break and subsequent continuation of a single utterance
- ? Rising intonation
- : Indicates prolongation of a sound
- Underlined: Emphasis in talk
- (.) Short pause in the speech
- [...] Extraction of speech turns
- - Single dash in the middle of a word denotes that the speaker interrupts herself
- -- Double dash at the end of an utterance indicates that the speaker’s utterance is incomplete
- Italics Context descriptions

**References**


**Figure legends**

Fig. 1: A reconstruction of the model depicting the solar panel function in the students’ textbook

Fig. 2: The explanation the students documented in OneNote of the function of the solar panels.

Fig. 3: The model that the students found on the Internet depicting the solar panel function ([http://astrofysikk.wikispaces.com/file/view/solcelle.jpg/76760605/solcelle.jpg](http://astrofysikk.wikispaces.com/file/view/solcelle.jpg)).