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Exploring Teacher Intervention in the Intersection of Digital Resources, Peer Collaboration, and Instructional Design

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ABSTRACT: This paper reports on a case study of the teacher's role as facilitator in computer-supported collaborative learning (CSCL) settings in science. In naturalistic classroom settings, the teacher most often acts as an important resource and provides various forms of guidance during students' learning activities. Few studies, however, have focused on the role of teacher intervention in CSCL settings. By analyzing the interactions between secondary school students and their teacher during a science project, the current study provides insight into the concerns that teachers might encounter when facilitating students' learning processes in these types of settings. The analyses show that one main concern was creating a balance between providing the requested information and supporting students in utilizing each other's knowledge and understanding. Another concern was balancing support on an individual versus group level, and a third concern was directing the students' attention to coexisting conceptual perspectives. Most importantly, however, the analyses show how teacher intervention constitutes the pivotal "glue" that aids students in linking and using coexisting aspects of support such as peer collaboration, digital tools, and instructional design. © 2015 The Authors. *Science Education* published by Wiley Periodicals, Inc. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made. *Sci Ed* **99:**837–862, 2015

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INTRODUCTION

The aim of the current study is to provide insight into teachers' concerns when facilitating students' learning processes in computer-supported collaborative learning (CSCL) settings. Numerous digital learning environments and resources have been developed with the aim of introducing students to scientific concepts (Linn & Eylon, 2011; Quintana et al., 2004). In keeping with this accelerating development, many science classrooms have begun using digital learning resources. Often these digital resources are used in educational settings where students solve open-ended tasks in collaboration with peers and with a teacher who actively guides and participates in the students' development of conceptual understanding.

Several studies have provided valuable knowledge about how to support students' learning processes through use of digital tools (Rutten, van Joolingen, & van der Veen, 2012; Smetana & Bell, 2012), peer collaboration (Howe, Duchak-Tanner, & Tolmie, 2000; Mercer, 2004), and various instructional designs (Linn & Eylon, 2011; Scardemalia & Bereiter, 2006). In most of this research, the analysis focuses on the impact of one or two forms of support. In naturalistic classroom settings, however, various forms of support are present at the same time, which implies that students' learning processes take place at the intersection of different and often coexisting forms of intended support. In addition, in settings where students engage in computer-supported activities, the teacher most often acts as an important resource, providing different forms of guidance during the students' learning activities. Although there seems to be general agreement that teacher support is crucial in computer-supported learning settings, few studies have analytically scrutinized its specific role, especially in CSCL settings (Greiffenhagen, 2012; Urhahne, Schanze, Bell, Mansfield, & Holmes, 2010; Webb et al., 2009).

The current study adds to this body of research by focusing on teacher interventions that support students' development of conceptual understanding in interactions that take place at the intersection of digital resources, peer collaboration, and applied instructional design. To demonstrate the complexity of facilitating students' development of conceptual understanding in these types of settings, we have performed detailed analyses of student and teacher interactions during a student project. In this case study, upper secondary school students designed virtual models of carbon dioxide (CO_2) friendly houses based on scientific theories about energy supply and heat loss from low-energy buildings.

Our analysis focuses on conceptually oriented talk (Furberg, Kluge, & Ludvigsen, 2013), sequences in which the students' and/or teacher's attention is directed to making sense of conceptual issues or, in this case, their talk about heat transfer. Our analytical focus is guided by our interest in exploring the concerns encountered by teachers in settings where students' development of conceptual understanding takes place at the intersection of digital resources, peer collaboration, and instructional design. We analyze student–teacher interactions using van de Sande and Greeno's (2012) conceptualization of "perspectival framing." This perspective enables a combined focus on the participants' social organization during their interaction and how they make sense of conceptual issues.

Research on Support of Students' Conceptual Understanding

Several researchers have pointed out that few studies focus on the role and significance of teacher intervention in CSCL settings (cf. Greiffenhagen, 2012; Urhahne et al., 2010; Webb et al., 2009). Based on analyses of teacher–student interactions in a naturalistic CSCL setting, Greifenhagen (2012) explored teachers' focus in interactions with students during group-work activities. The study reported that teacher interventions targeting conceptually oriented issues, also known as "pedagogical aspects," are intertwined with teacher interventions targeting classroom management issues. Other studies have focused on the effects of teacher intervention in CSCL settings, and these studies have shown positive effects on students' conceptual understanding when the teacher provides indirect intervention, for instance by prompting questions or encouraging students to retrieve science-based information instead of providing descriptive explanations or prompting fact-based student responses (Hakkarainen, Lipponen, & Järvelä, 2002). Furthermore, a study on students' help-seeking behavior in CSCL settings showed that students sought less help but showed higher learning gains when the teacher provided consolidation instructions in the form of introductions to new tasks, evaluations, and discussions of results in plenary sessions (Mäkitalo-Siegl, Kohnle, & Fischer, 2011).

Our review of studies that have focused on aspects of support other than teacher intervention showed that the studies emphasized one or more of the following aspects: *digital resources, peer collaboration*, and *instructional design*. The majority focused on how various digital resources or tools embedded in computer-based inquiry environments could support student learning. Examples of digital resources are dynamic or static visualizations, computer simulations, interactive tasks, collaboration- and argumentation-supporting tools, domain-specific text, etc., designed to represent a scientific phenomenon and/or central scientific concept (Bell, Urhahne, Schanze, & Ploetzner, 2010; de Jong et al., 2012; Linn & Eylon, 2011). Several studies reported positive effects on students' learning as a result of engaging with various types of computer-mediated representations such as simulations (Rutten et al., 2012; Smetana & Bell, 2012), multiple representations (Ainsworth, 2006), and virtual labs (Baltzis & Koukias, 2009; Kozma, 2003; Zacharia, 2007). In these studies, student learning was primarily measured using pre- and posttests. Despite the consensus on the positive effects of digital support tools on student learning, some studies have also reported challenging findings. For instance, students often have difficulty seeing relationships between different representations of the same phenomenon (van der Meij & de Jong, 2006) or tend to focus on the surface features instead of the underlying scientific principles (Ainsworth, 2006).

Other studies have focused on the influence of peer collaboration in computer-supported settings. Research based on various learning perspectives has emphasized the advantages of peer collaboration in enhancing student learning (Howe et al., 2000; Linn & Eylon, 2011; Mercer, 2004; Scardemalia & Bereiter, 2006; Stahl, 2006). For instance, several studies have found that peer collaboration helps students develop scientific argumentation skills (Linn & Eylon, 2011; Littleton & Howe, 2010), conceptual understanding (Bell et al., 2007; Howe et al., 2007; Linn & Eylon, 2011), inquiry learning skills (van Joolingen, de Jong, & Dimitrakopoulou, 2007), and productive disciplinary engagement (Clark & Sampson, 2007; Engle & Conant, 2002). However, studies have also revealed challenging aspects of peer collaboration. Student talk and collaboration must be cultivated over time, and researchers have pointed to the importance of students learning to deal with disagreements and opposing views on scientific explanations or the problem to be solved (Howe et al., 2000; Mercer, 2004).

Other studies have focused on the impact of the instructional design on student learning processes. A common feature of design-based research is a focus on computer tools or task interventions whose design is informed by idealized models of productive learning. Various instructional models have been developed based on socioconstructivist theories of learning, such as "knowledge building" (Scardemalia & Bereiter, 2006), "progressive inquiry learning" (Muukkonen, Hakkarainen, & Lakkala, 1999), and "knowledge integration" (Linn & Eylon, 2011). Another instructional design model based on similar ideas is the jigsaw model (Aronson, Bridgeman, & Geffner, 1978; Brown et al., 1993), which was the instructional design used in the current study. By breaking classes into groups and assignments into pieces, the jigsaw model organizes classroom activity to make students dependent on each other to succeed. Several studies have documented positive effects of the jigsaw method on students' learning compared to more traditional teacher-centered and individualized methods (Doymus, Karacop, & Simsek, 2010; Karacop & Doymus, 2013; Tarhan & Sesen, 2012). However, as with all instructional designs, studies have also reported lower or equal academic performance by students under the jigsaw condition compared to more traditional work forms (Hänze & Berger, 2007; Souvignier & Kronenberger, 2007; Zacharia, Xenofontos, & Manoli, 2011).

To summarize, although many studies on science learning in computer-based settings have provided valuable knowledge to the field, we nevertheless stress the value of taking a different analytical approach to provide deeper insight into the role of teacher intervention in these types of settings. In most science classrooms where digital tools and learning environments are used, the teacher orchestrates the support aspects of digital resources, peer collaboration, and instructional design to facilitate students' development of conceptual understanding. By taking an ecological perspective that focuses on teacher interventions taking place at the intersection of digital resources, peer collaboration, and an applied instructional design, and by performing detailed analysis of student–teacher interaction over time, this study aims to provide deeper insight into concerns encountered by the teacher in CSCL settings.

Approaching the Role of Teacher Intervention From a Sociocultural Perspective

Seen from a sociocultural perspective, the teacher holds an important position in students' learning processes (Furberg & Ludvigsen, 2008). First, by virtue of being a scientific expert, the teacher acts as an important conceptual resource for the students. However, the teacher also holds an important position as the facilitator of the learning activities and the instructional design (Squire, MaKinster, Barnett, Luehmann, & Barab, 2003). In addition, the teacher becomes a provider of institutional practices and norms (Mehan, 1991; Mercer, 2004) reflected, for instance, in the assessment criteria, which include expectations regarding how to participate in group work, how to behave in front of a teacher, or how to solve a task appropriately. The relationship between teacher intervention, the tools in use, peers, and instructional design is interdependent: They each influence students' conceptual development in the activity setting. In other words, students' conceptual understanding develops at the intersection of these aspects (Säljö, 2010).

From a sociocultural perspective, learning is seen as a dynamic and dialogical meaning-making process between interlocutors (Linell, 2009; Vygotsky, 1978; Wertsch, 1991). Through their interactions, participants try to interpret and make sense of situations, actions, and scientific concepts. At the same time, the participants make their own interpretations visible and observable to other participants. In this sense, language is seen as the most important tool for making sense of the world, human practices, and ideas and as a tool that mediates thinking and reasoning (Vygotsky, 1986). Talk and discourse are therefore conceived of as a "social mode of thinking" (Mercer, 2004).

Meaning is dialogically constituted in specific practices, and meaning-making involves complex interactions among people, resources, and the organization of the setting (Stahl, 2006). An important part of human conduct and learning processes is the use of various material tools (Säljö, 2010). These can be seen as cultural artifacts that store knowledge and social practices developed over generations (Cole, 1996). This interpretation implies that digital learning environments—often containing representations such as graphs, visualization models, or simulations—are developed to display and represent experts' knowledge about objects, processes, or phenomena. Students interact with the knowledge and practices stored within digital learning environments when they utilize these representations in their learning activities (Säljö, 2010). In this sense, digital learning environments, such as the SCY-Lab with its embedded digital tools, can be seen as resources for students' development of conceptual understanding.

When engaging with science, students are asked to make sense of diverse concepts. Scientific concepts do not embody fixed or universal meanings but come with historic "meaning potentials" that need to be elaborated on and made relevant to students (Linell, 2009). However, this does not imply that students can come up with just any explanation for a scientific concept. All science domains have cultural contexts that include commonly expressed understandings and ways of talking about conceptions, implying that some ways of representing and talking about scientific concepts are seen as more "correct" or valid than others (Wertsch, 1991). From this perspective, teachers facilitating students' learning processes in computer-supported collaborative settings enforced by various instructional designs must do more than just provide instructional support; they must also orchestrate coexisting support aspects, each with its own affordances and constraints.

The aim of the study is to contribute to the conceptualization of the complexity of teacher intervention within computer-supported learning activities. With an analytical focus on teacher interventions at the intersection of digital resources, peer collaboration, and instructional design, we address the following research question:

RQ: What concerns does the teacher encounter in student–teacher interactions when facilitating students' development of conceptual understanding in CSCL settings?

RESEARCH DESIGN

Design of Learning Activities and Resources

The data in this paper were produced during an intervention study as part of the Science Created by You (SCY) project. The current study is informed by ideas from design-based research (Collins, Joseph, & Bielaczyc, 2004). The objective is to examine interaction and learning in a naturalistic setting but, at the same time, to also study the influence of specific design principles. We used a sociocultural design–based approach; the main difference between this approach and a more "traditional" design-based approach is the status of the design principles in the empirical analysis of the activities and/or learning that takes place during the design experiment (Krange & Ludvigsen, 2009). For instance, in Collins and colleagues' (2004) design-based approach, the design principles are used as the basis both when designing a learning environment and when evaluating the effectiveness of the intervention. In contrast, a sociocultural design–based approach implies that design principles are used in designing learning activities; however, the same design principles are not used as an analytical framework when analyzing the activities and interactions taking place during the intervention. This ensures that the concerns of the participants and their actual activities are scrutinized—not only the researchers' intentions and predefined interests.

Central to the project was the development of the computer environment, the SCY-Lab, which contains various science-related learning modules (de Jong et al., 2012). In the current empirical setting, students were to learn about energy supply and heat loss, and their main task was to design a virtual model of a CO_2 friendly house based information from a variety of resources such as textbooks, Internet-mediated sources, and a heat loss simulation tool embedded in the SCY-Lab. Using the simulation tool, the students calculated the heat loss

TABLE 1
Overview of Project Activities

Day #	Organization	Activity
Day 1	Plenary session	Lecture about energy supply and heat loss from low-energy buildings by visiting expert
	Basic groups	Group task on concept map related to energy supply and heat loss
Day 2	Expert groups	Group 1: Heat loss and insulation
	(Jigsaw model)	Group 2: Heat pumps
	Teacher lecture	Group 3: New renewable energy
	in each field	Group 4: Solar energy
Day 3	Basic groups	Peer-group presentations of individual expert fields
Day 4 + 5 + 6	Basic groups	Design and construction of virtual, CO_2-friendly house with the use of heat loss simulation tool
Day 7 + 8	Basic groups	Preparation for the group presentation
Day 9	Plenary session	Group presentation

of the construction materials used in the virtual house model. The concepts of heat loss (J) and heat transfer coefficient (W/m^2K) were central in the curriculum design. Heat is central to the school science curriculum and is frequently brought up in public discussions about the use of renewable energy in the construction of buildings and private homes.

The participants were 42 upper secondary school students, aged 16–17 years, and two teachers from two general science classes. The two teachers, both in their 10th year of practice, were recruited by the school's principal based on their experience and competence as professional teachers. The project was carried out in 20 school lessons, 45 minutes each, over the course of 2 weeks (see Table 1 for an overview of the project schedule). The design experiment took place at a school situated in Oslo, Norway, as part of the standard instruction schedule.

The SCY-Lab environment was developed by an international project team consisting of programmers, teacher educators, and educational scientists within the SCY project. The design experiment was planned and executed by our local research group. The overall aim of the design experiment was to create a learning setting where we could explore and analyze students' development of conceptual understanding as they use digital learning resources, combined with an instructional design aimed at probing conceptually oriented peer interaction that also included teacher intervention in the form of group guidance. The instructional design and learning activities were planned in collaboration with the two teachers. During this planning phase, the researchers emphasized the significance of peer interaction in the form of conceptually oriented discussions and group-oriented teacher intervention, but the teachers were not given specific instructions on how to facilitate peer interaction and group-oriented teacher intervention. During the design experiment, the teachers, as professional practitioners, had full responsibility for implementing the instructional design without interference from the observing researchers.

Instructional Design, Student Work Forms, and Teacher Intervention

The instructional design was informed by the jigsaw model (Aronson et al., 1978; Brown et al., 1993). This model organizes classroom activity in such a way that students within the same group become experts in different fields. Student collaboration is common in the participating school; however, the particular work form of jigsaw-based instruction used

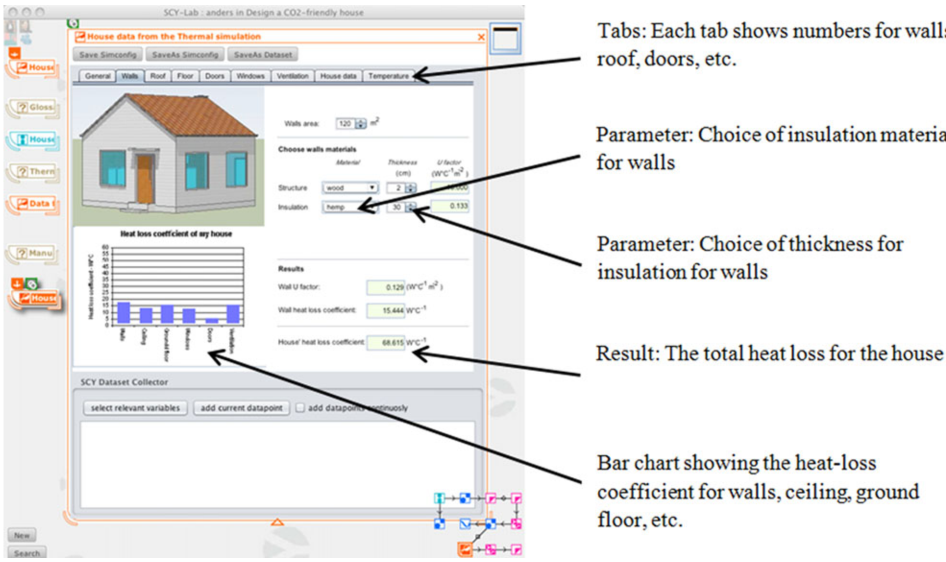

Figure 1. The heat loss simulation tool in SCY-Lab.

in this case was new to the students. Central to the instructional design were the "expert group" sessions during three school lessons at the very beginning of the project. The expert groups, each consisting of three to five students, were given one of four designated "expert fields" to focus on: "heat loss and insulation," "heat pumps," "solar panels and solar thermal collectors," and "new renewable energy." A teacher lectured the expert students in each assigned field. After listening to the teacher, each expert group was asked to produce a one-page written account of the expert topic; the students then reorganized themselves into new groups (termed "basic groups") consisting of one student from each of the four expert groups, and each expert was presented his or her topic of expertise to his or her peers. The goal of the activity was for all students in the groups to gain insight into all expert fields. After the presentations, the groups were asked to design their own virtual, CO_2 friendly house models to present to their class at the end of the project. During the project, the teachers circulated among all the student groups.

The Heat Loss Simulation Tool in the SCY-Lab

A central tool in the SCY-Lab for introducing the students to the concepts of heat transfer coefficient and heat loss was the heat loss simulation tool (see Figure 1), which the students used to calculate how the different construction materials would affect the total heat loss for each house element.

The heat transfer coefficient and heat loss are complex concepts and can be understood from several perspectives. In this study, the teacher explicitly advocated two different perspectives on heat loss. One perspective is the phenomenon perspective (later referred to as "phenomenon framing"): that is, an understanding of heat referring to the thermal energy transferred from one system with a higher temperature to another system with a lower temperature. The second perspective was the formula perspective (later referred to as "formula framing"), in which calculating the heat requires the capacity to see the relation between this concept and other concepts (i.e., power [W] and energy [J])—concepts that, in themselves, can be seen as complex for students. The formula for calculating heat loss

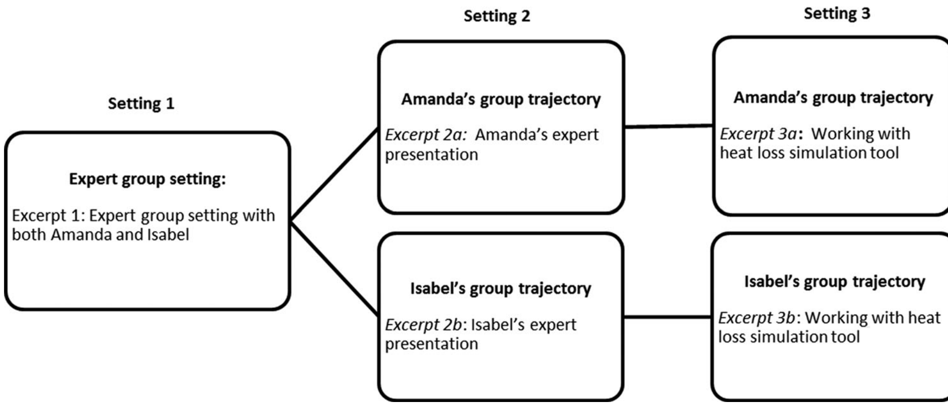

Figure 2. The figure shows the situations from which the excerpts are taken.

is related to the concept of heat transfer coefficient, which is defined as the rate of heat transfer through a building element per square meter per degree of temperature difference (W/m^2K). The engineering notion for the heat transfer coefficient is the U-factor. The concept of U-factor was used in the simulation, and, thus, the students and teachers used the engineering notion when they talked about the heat transfer coefficient.

Data and Analytical Procedure

Three focus groups of four students each were videotaped during the project. The three groups were selected with the teachers' help, based on the criterion of being verbally active. According to the teachers, the students were average- to high-level achievers in science. Our data consisted of 40 hours of transcribed video recordings of the focus groups' interaction, along with field notes taken during classroom observation that were used to contextualize the data.

In this case study, we performed detailed analyses of two students' interactions with their respective peer groups and the teacher. Our analysis focuses on two students, Isabel and Amanda, and how they, together with their peer groups and the teacher, make sense of the concept of heat transfer coefficient. As shown in Figure 2, five interaction excerpts were selected from the two students' interaction trajectories and then analyzed in detail. In accordance with our focus on the role of teacher intervention, we selected excerpts from settings where the teacher engaged with the student groups. Amanda and Isabel participated in the expert group on "heat loss and insulation," and the first analyzed excerpt is from this expert group. In the second part of the analysis, we follow Amanda and Isabel in their two separate basic groups, first in a setting where they present the information and experiences from their expert group session and then in a group-work setting in which the students were to design a virtual house model.

We focused on the interactions between Amanda, Isabel, and their two respective peer groups for several reasons. These two students and their peers were verbally active students. Furthermore, a conceptual topic in Amanda's and Isabel's expert group sessions—the heat transfer coefficient—appeared several times during their basic group discussions as well as in student–teacher interactions. This ongoing verbalized activity in the two groups made the students' development of conceptual understanding transparent in such a way that we are able to analyze in detail how their understanding of heat transfer coefficient developed in the intersection of teacher intervention, digital resources, peer collaboration, and instructional design. Another reason for focusing on these two students and their peer groups is that the two groups' discussions and work forms differ greatly from one another. Consequently, a dual focus on both Amanda and Isabel and their respective groups enables us to address *variations* in students' development of conceptual understanding, as well as variations in how the teacher intervened.

By analyzing the selected chronological excerpts of the students' interaction trajectory, we are able to show the evolving development of the students' conceptual understanding as well as the opportunities and challenges of teacher intervention in these types of settings. We use the notion of *interaction trajectory* to refer to the analysis of interactions over time (Furberg & Arnseth, 2009; Ludvigsen, Rasmussen, Krange, Moen, & Middleton, 2011). By exploring students' interaction trajectories, we can investigate the changes that take place in students' sense making of the specific domain content as well as how different support aspects influence their sense-making processes. In addition to detailed examinations of specific interaction excerpts, we used ethnographic information documented in video recordings and field notes as a background resource for describing the educational setting. In the discussion and conclusion, we tie our analytic generalizations back to the larger corpus of data, analysis of the extracts, our theoretical grounding, and the literature review.

We used the analytical procedure of interaction analysis, which implies that talk and interaction between interlocutors are analyzed sequentially (Furberg et al., 2013; Jordan & Henderson, 1995). This means that each utterance in a selected sequence is understood and seen in relation to the previous utterance in the ongoing interaction. This practical guideline for analysis supports the idea that analytical descriptions are oriented toward interactional achievements and not what might be taking place in individuals' minds (Linell, 2009).

In our analysis of the student–teacher interactions, we also use a set of analytical concepts on "perspectival framing" adopted from van de Sande and Greeno (2012). Here, framing refers to the way in which participants understand the activity in which they are engaged. We specifically focus on two interrelated aspects of framing: the first aspect, "conceptual framing," refers to the way in which participants, in this case the students and the teacher, organize information by bringing it to the foreground or background of their attention when they try to achieve mutual understanding of a concept or problem. In the current study, by making use of this concept of framing we are able to show which aspects of heat students attend to. For instance, the students may relate to the concept of heat by foregrounding the phenomenon of heat loss, which in this case is how to isolate a house to minimize heat loss and how heat is transferred through different types of materials as a result of a temperature difference between two systems (phenomenon framing). Students may also work with the concept of heat by foregrounding the formula, which in this case is how to calculate heat loss for different building materials using the heat transfer coefficient (formula framing). A central issue of the participants' development of mutual understanding is what van de Sande and Greeno called "alignment of conceptual framing," which refers to whether the participants interactionally develop common ground and "achieve mutual understanding" of how to organize information when solving a task.

The second aspect of framing, "positional framing," concerns the way participants understand themselves and one another in interactions, "especially regarding the contributions each of them is entitled, expected, and perhaps obligated to make in the group's activity" (van de Sande & Greeno, 2012, p. 2). In small-group settings, students collaborate to solve the task by adopting specific positional framings: "source" and "listener." The source is the person or object that provides information another person needs to understand the issue at stake, and the listener tries to interpret the source for mutual understanding.

By using the analytical concepts of perspectival framing, i.e., positional framing and conceptual framing, we are able to show that social processes and individuals' development of conceptual understanding are intertwined. At the same time, the analytical concepts make it possible to identify how each individual contributes in the mutual development of conceptual understanding. In turn, using these analytical concepts provides deeper insight into the complexity encountered by the teacher in supporting students' development of conceptual understanding.

RESULTS

The excerpts analyzed here are from three subsequent sessions in the project during which the participants discussed heat transfer. In the initial project phase, the instructional design was based on the previously described jigsaw model. The students were organized in expert groups specializing in a particular field and prepared a manuscript to present to their peers in the basic groups. The expert group analyzed below specialized in heat and heat loss, and the expert group session started with the teacher lecturing on heat transfer and insulation of low-energy buildings. In his lecture, the teacher explicitly emphasized the two conceptual framings of heat transfer coefficient and heat loss: phenomenon framing and formula framing. After the lecture, the students focused on group-work activities and browsed the Internet for relevant information to include in the manuscript. During the group-work activity, the teacher circulated among the groups and engaged in their discussions. Below, five interaction excerpts are analyzed. The first setting is from the expert group focusing on heat loss and insulation, in which Amanda and Isabel participated. Subsequently, we follow Amanda's and Isabel's interaction trajectories as they split up and go back to their basic groups to share the information and experiences from the expert group session.

Setting 1: The Expert Group Session: Unpacking the Heat Transfer Coefficient Formula

In the following episode, Isabel and Amanda, and their peers Mia, Magnar, and Lisa, are preparing for their individual basic group presentations. The students are sitting around a table with their laptops in front of them. Mia has summoned the teacher and asked him to read their manuscript. Thus far, the students have written about how to keep heat inside the house. After reading the manuscript, the teacher points out that they need to include the concept of heat transfer coefficient. Picking up on the teacher's suggestion, Amanda asks the teacher to explain, and we enter the discussion when the teacher is about to give his explanation.

Excerpt 1 (see Table 2) begins with the teacher using a simplified example to explain the formula for calculating the power needed to heat a house with fixed dimensions. Amanda and Isabel follow up with specific inquiries. Using the responses provided by the teacher, the three collectively unpack the heat transfer formula by building on each other's input (lines 5, 7, and 9). Amanda's use of the conclusive term "so" in line 11 indicates that she has come to some kind of understanding, and for the first time she tries out a more cohesive verbalized explanation of the heat transfer formula. The teacher confirms Amanda's statement by nodding. Isabel's immediate response in line 13, opening with the discourse marker "but," indicates she finds something is inconsistent or difficult to understand. However, instead of explicating what this is, she withdraws by saying "just kidding." The teacher, Amanda, and the other students do not prompt Isabel to explain her concerns.

If we look at Isabel's contributions in the rest of the excerpt, it becomes clear that at this point she withdraws from providing conceptually oriented queries and inferences. Amanda, however, continues to provide inferences to which the teacher responds and confirms (lines 14 and 16). In line 18, Amanda states that she understands, to which Isabel adds somewhat humorously, that Amanda, who has explicitly expressed her understanding, can take on

TABLE 2
Excerpt 1

1.	Teacher	Let's say you have 400 square meters of wall, ceiling, and floor in the house
2.	Amanda	Yes
3.	Teacher	And the mean value of the U-factor [*heat transfer coefficient*] for the entire house is one. That is, in order to keep a stable temperature inside the house, which is one degree higher than outside the house, you will need a 400-watt electric heater
4.	Isabel	Oh, my God! ((*yawning and leaning backwards*))
5.	Amanda	400 watts (.) What do you mean? 400 watts of what?
6.	Teacher	A 400-watt heating supply inside
7.	Isabel	Because it's 400 square meters? ((*sits upright again*))
8.	Teacher	400 square meters and the mean value for the U-factor is one--
9.	Isabel	And then you'll need one watt per square meter
10.	Teacher	((*nods*))
11.	Amanda	So, it's like watts multiplied by um (.) no, no (.) The size is multiplied by the U-factor in order to find out how much wattage we need?
12.	Teacher	((*nods*))
13.	Isabel	But here ((*points to the computer screen containing her notes from the teacher's lecture*)), you found two different things then. Because here you found--No, I was just kidding
14.	Amanda	So, in order to find that U-factor, you take the watt--
15.	Teacher	But this applies to each degree temperature difference between inside and outside
16.	Amanda	So, if there is a difference of 10 degrees, you'll need 400 times 10 watts? Four thous--
17.	Teacher	4000 watts ((*nods))*
18.	Amanda	But, then I think I understand it
19.	Teacher	That's great
20.	Isabel	Great, Amanda. Then you can write the manuscript ((*laugh*s)). No, I am just kidding
21.	Teacher	If you're able to explain this to the others, that would be excellent
22.	Amanda	Because if the U-factor is low, you might not need as many watts as well
23.	Teacher	Right, and then you can use less energy in heating
24.	Amanda	Then you save more electrical energy
25.	Teacher	((*nods*))
26.	Amanda	Oh, yes, then I understand it. We need to write that down ((*pointing at Mia who is writing the manuscript*))
		((*The teacher leaves the room, and the students continue working on their joint manuscript. When the students write about the U-factor in the manuscript, Amanda is the one who dictates what Mia writes*))

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 speech (.) Short pause in speech (# of seconds) The time, in seconds, of a pause in speech [. . .] Utterances removed from the original dialog - 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)) Annotation of nonverbal activity.

the job of finishing their manuscript. The teacher picks up on Isabel's shift in focus, and emphasizes once more the importance of explaining the heat transfer coefficient to their peers. The episode ends with Amanda checking another specific detail with the teacher, before focusing on what they need to include in their manuscript (line 22).

By applying van de Sande and Greeno's concept of positional framing to Excerpt 1, we can highlight two distinctive aspects of the participants' contributions. The first aspect concerns changes in the participants' positional framing: changes in who is providing information (the source) and who is requesting and interpreting information (the listener). Our analysis of the interaction shows that from the beginning the teacher took the source position by responding to the students' inquiries about the heat transfer coefficient. Amanda and Isabel took the position of constructive listeners by posing inferences and inquiries along the way. Isabel's withdrawal toward the end, however, can be seen as a change in her positioning from a constructive listener to a more passive listener. Amanda undergoes a more substantial shift in positional framing, toward taking the source position. When Amanda provided cohesive reasoning about the heat transfer coefficient and stated she understood, her peers, voiced by Isabel, suggested that she should be responsible for writing the part about the heat transfer coefficient in their document. In other words, Isabel invoked Amanda as a possible source. Amanda's utterance toward the end of the excerpt signals that she acknowledged and took on the appointed role as source when she asserted that they needed to put the things they had talked about in the manuscript.

The second analytical aspect concerns the teacher's elicitation of the students' understanding, or a lack thereof. In the opening, the teacher responded to both Isabel and Amanda's concluding inferences. From the point where Isabel withdrew, though, the teacher's main attention was on Amanda. In addition, the teacher did not pick up on Isabel's query when she signaled that she saw inconsistencies in their joint reasoning. Furthermore, the teacher did not prompt the other students to explicate their understanding. These interactions in Excerpt 1 show the challenges that most teachers face in group-work settings: balancing supporting an individual student's understanding with the group's mutual understanding. As we will see in the following, the variations in the students' understanding of the concepts had consequences for the interactions in both Amanda and Isabel's basic groups in which the two, in the role of expert students, were to provide a detailed explanation of the concept heat. In Excerpts 2a and 2b, we follow Amanda in her basic group.

Amanda's Interaction Trajectory in Her Basic Group

Setting 2a: Amanda's Expert Presentation. In Excerpt 2a (see Table 3), the expert students are back in their basic groups where they are to provide a short introduction to their designated expert topic. Amanda is the last one in her group to present. In terms of conceptual framing, Amanda approaches heat loss and insulation within two conceptual framings: first within phenomenon framing by explaining the importance of insulation for keeping the heat inside the house and then within formula framing, when she explains how to calculate the heat transfer coefficient. During her presentation, the teacher enters the room quietly. Standing in the background, he listens to Amanda's presentation. We enter the setting when Amanda is about to finish her presentation.

The excerpt starts with Amanda giving a complex and somewhat imprecise account of heat and the heat transfer coefficient. For instance, she uses the domain-specific terms watts, joules, heat, and heat transfer coefficient without elaborating on their meaning and provides vague formulations and explanations such as "release the U-factor (heat transfer coefficient)" and "the U-factor (heat transfer coefficient) is the way you calculate power" (line 1). However, regardless of Amanda's dense and unelaborated account of the heat

TABLE 3
Excerpt 2a

1. Amanda	The U-factor [*heat transfer coefficient*] is the way you calculate how many watts are needed in order to keep the house warm and how much insulation and such. The U-factor is the watts divided by meters squared multiplied by the temperature difference. [. . .] Then you will find the number of kilojoules being released, and then you know that you at least need so many watts in order to keep the heat inside. And preferably more watts than that. And that also affects insulation. If you have bad insulation, then you will release a lot more U-factor, right. And therefore you will need a lot more electrical power. Did you get it? So, you see the connection, don't you?
2. Linnea	Yes ((*yawning*))
3. Ole	Yes
4. Amanda	You understood this, right? It isn't very complicated. You only have to change and switch the formula when you want to find the different numbers and values. [. . .] Yes, this is really all I had ((*smiling*))
5. Ole	Then we are finished? ((*looking at the teacher*))
6. Teacher	What have you learned? ((*looking at Ole*))
7. Ole	Learned and learned. Like (2) like, there are practical solutions, for ventilation and such, that I didn't know about how it functions, and that it was a rather smart thing with the hot air inside that heated outside air coming in. That was quite logical, but I didn't know that
	[. . .]
8. Teacher	The U-factor, did you understand any of that? It's a difficult concept to understand in a way ((*looking at all the students*))
9. Linnea	I did at least learn something about it
10. Teacher	In such a way that you are able to see it as more than a number?
11. Amanda	I think I was able to explain it quite well
12. Teacher	That's great ((*giving a thumb's-up sign*))
	((*The teacher leaves the students after a short conversation about what the next task will be*))

transfer coefficient, Linnea and Ole explicitly confirm their understanding when Amanda asks if they have understood what she has explained (lines 2 and 3). Ali, however, remains silent. Sensing that the students consider themselves ready to move on to another task, the teacher interrupts and asks Ole what he has "learned" by listening to Amanda's presentation (line 6). Ole responds to the teacher's question by using the phrase "learned and learned"[1] (in Norwegian, *lært og lært*), which can be interpreted as a way of expressing that he has *perceived* some of the things Amanda explained, which is not the same as *understanding* everything she said (line 7). Then Ole gives an example of something he did understand, which was the part about heat recovery ventilation. After listening to Ole's account of the recovery ventilation, the teacher asks if the students understood what Amanda said about the heat transfer coefficient and adds that this is a complex matter (line 8). Linnea responds, "I did at least learn something about it," indicating that she, like Ole, understood some of the things that Amanda explained to them, but also that some parts were harder to grasp (line 9). Again, the teacher provides an understanding-oriented request and emphasizes the

[1]The phrase *lært og lært* represents what is termed an X-och-X construction in Swedish (Lindström & Linell, 2007), which is also used in Norwegian. This is a reactive pattern: Repeating a previously used term twice signifies that the previous utterance was not quite adequate.

importance of seeing the U-factor as more than just a value. Before any of the addressed students answer, Amanda interjects with a positive validation of her own performance, to which the teacher provides a positive appraisal and leaves (line 12).

By focusing on the participants' positional framing, i.e. their positioning as sources that provide information or as listeners that are requesting and interpreting provided information, we can highlight some concerns encountered by the teacher and students. In this setting, Amanda had the designated position of an expert on heat, a position she accepted. Focusing first on Amanda's peers, the absence of follow-up questions combined with the students' ambiguous utterances about what they have "learned" can be seen as evidence that they found it difficult to relate to their expert peer, as well as an expression of their difficulty with challenging their expert peer to provide a better or more extensive explanation.

Turning the focus to the teacher's positional framing, the analysis shows that in this setting the teacher placed himself quietly in the background when Amanda was presenting. He did not interrupt her presentation, and he did not interfere by providing elaboration or supplementary information, even if he might have perceived that the other students were uncertain. Instead, he limited himself to directing the students' attention toward focusing on the heat transfer coefficient, along with asking them whether they had understood the concept. In other words, when the teacher refrained from taking a source position, he was left in the middle, neither a source nor a listener. This situation seems to be a double-edged sword in that the teacher risked undermining the expert student's role as the designated source if he took the source position. However, by allowing Amanda's peers to "get away with" stating their (partial) understanding instead of making them accountable for displaying their understanding, the teacher put himself in a position in which he was incapable of knowing what the students did and did not understand.

Concerning the participants' conceptual framing, Excerpt 2a shows that the teacher attempted to emphasize the importance of both phenomenon framing and formula framing. Both framings were addressed by Amanda in her presentation. When prompted to account for what they had learned from Amanda, her peers mainly provided phenomenon framings of heat. Consequently, the teacher's method of directly prompting Amanda's peers about their understanding of the heat transfer coefficient was a way of confirming that the students' attention was directed not only at phenomenon framing but also at formula framing.

Setting 3a: Working With the Heat Loss Simulation Tool. Before the following excerpt (see Table 4), Amanda and Ali had worked for a while with the simulation tool in the SCY-Lab. This tool explicitly addresses the heat transfer coefficient and helps students calculate it for different building elements for their virtual house. Ali and Amanda browse the Internet for information about the Norwegian requirements for house insulation. When the teacher enters the room, Ali seizes the opportunity to ask the teacher about the variation in different materials' heat transfer coefficients. While the two talk, Amanda continues browsing the Internet for information.

The excerpt begins with Ali wanting to know whether a *high* or *low* heat transfer coefficient value indicates the best heat loss result, since he observed from interacting with the simulation tool that steel has a much higher heat transfer coefficient than wood (lines 1 and 3). The teacher responds, "Steel conducts heat very well." Ali seems to interpret the teacher's statement "conducts heat very well" as a positive quality and infers that steel would be a better choice than wood for the exterior material (line 5). This implies that Ali infers that a high heat transfer coefficient is validated as better than a low coefficient, and, consequently, materials with a high heat transfer coefficient are better to use for insulation.

TABLE 4
Excerpt 3a

1.	Ali	Steel has a U-factor [*heat transfer coefficient*] of 1000
2.	Teacher	Uhum
3.	Ali	And wood and such have only four. Why is there such a big difference?
4.	Teacher	Steel conducts heat very well
5.	Ali	So, it's better with steel then? ((*referring to steel being a better exterior material in their house*))
6.	Teacher	No, you know, if you've got steel going through from the inside to the outside, then a thermal bridge, as one calls it, will appear because steel conducts heat very well. That is possible to feel for yourself if you've got a matchstick. It can burn all the way until the flame reaches your finger without getting very warm. If you take a nail, metal, you know.
7.	Ali	Uhum
8.	Teacher	And warm it at the end, then it won't take long before it has conducted the heat so much that you're not able to hold it
9.	Ali	Yea, that's true. But, what does high and low U-factor mean? Is it good with a high or low U-factor?
10.	Teacher	Amanda, what is best: a high or low U-factor?
11.	Amanda	Low is better. ((*Keeps looking at the computer screen*))
12.	Teacher	Uhum
13.	Ali	Then, it's better with wood than steel?
14.	Teacher	Uhum. The U-factor is a measure of energy flow ((*The conversation changes to another topic*))

The teacher picks up on Ali's incorrect inference and responds by explaining about thermal bridges: How a piece of metal gets warm very quickly when exposed to a flame. Ali's response signals that he understands the teacher's explanation of how steel is a better heat conductor than wood, but that he still grapples with determining whether a high or low heat transfer coefficient is considered the best when it comes to insulation quality (line 9). Instead of answering Ali's straightforward question, the teacher bounces the question over to Amanda, the designated expert on heat and insulation. Amanda responds that "low" is better, to which Ali infers that wood must be better than steel. The teacher confirms Ali's inference, and adds that the heat transfer coefficient measures energy flow.

In terms of the participants' positional framing in this setting, we see that in the opening of the excerpt, the teacher took the source position when he responded to Ali's inquiries about the meaning of high and low heat transfer coefficients. Ali took the listener position. Toward the end of the excerpt, however, the teacher redirected Ali's question to Amanda (line 9). By doing this, the teacher withdrew from the source position, just as he did in the last basic group setting (Excerpt 2a), and at the same time he invoked Amanda, the expert student, as the source.

Another aspect of the positional framing in this excerpt concerns the simulation tool's position as a source. The simulation was designed to help students understand the relevance of calculating the heat loss of insulation materials and to help them unpack the role of the heat transfer coefficient in the formula for calculating heat loss. Thus, the simulation supports a formula framing of heat. Ali's focus on the values calculated according to the formula shows that in this setting he foregrounded the formula framing. Furthermore, the interaction in Excerpt 3a (see Table 4) shows that the simulation did not provide enough support for Ali to understand the heat transfer coefficient or interpret high and low values for this coefficient. When responding to Ali's queries, the teacher explained by pointing to what happens to steel when it is exposed to flame. In other words, by using the steel example to explain the differences in materials' heat transfer coefficients, the teacher used a phenomenon framing of heat to explain heat from a formula framing. Based on the teacher's linking of conceptual framings, Ali then correctly concluded that wood is better than steel for exterior use.

Before we end the analysis of Amanda and her peer's group work, we will describe their conceptual framings of heat in their plenary presentation at the end of the project. In the presentation, the students emphasized the heat transfer coefficient. Amanda explained how to calculate the heat transfer coefficient, presented values for it, and based her final argument on why their house was a low-energy building on this concept. She compared the house's total heat loss with the requirements for heat transfer coefficients for low-energy buildings. Our interpretation is that formula framing was in the foreground in the students' presentation, whereas phenomenon framing was in the background.

Isabel's Interaction Trajectory in Her Basic Group

Setting 2b: Isabel's Expert Presentation. We enter Isabel and her group's interaction trajectory when Isabel is about to finish her 10-minute expert presentation. She ends by asking if any of her peers have questions. One student asks Isabel to elaborate on the concept of heat transfer coefficient, and in the following excerpt, Isabel is about to reply to this request.

In the opening of Excerpt 2b (see Table 5), Isabel, the designated expert, explains that a low heat transfer coefficient means that the house does not emit much air, and then adds that insulation prevents wind from entering the house (lines 1 and 2). Mary, who is trying to understand, follows up by asking an inferential question. By using the discourse marker "but," she signals she does not understand what Isabel is saying. Mary confirms that she understands what Isabel says about the insulation stopping the wind, but points out that she still wants to know whether the insulation warms up incoming cold air as well as letting the warm air pass into the house (lines 3, 5, and 7). By responding with an initial "No," Isabel signals that Mary's inference is wrong and continues by emphasizing that not all but some of the air will enter the house (line 8). Seemingly unsatisfied with Isabel's answer, Mary repeats her question about whether the insulation warms up the incoming cold air. The tone in her voice indicates that she is getting frustrated. At this point, Elise interjects, and says that she does not understand what they are talking about. The tone of her voice signals that she also is becoming frustrated (line 10). In lines 12 and 14, Isabel tries again to explain how insulation works. In her explanation, she still focuses on how insulation stops wind from entering the house, but she also provides a more elaborated account of ventilation. Mary's question about whether the insulation warms the incoming air remains unanswered. Elise's "si, si" (pronounced with an Italian accent) (line 13) can be interpreted as a signal that she accepts Isabel's explanation without necessarily understanding or agreeing with it. Isabel's wind-stopper explanation remains unchallenged, as Malin (line 15) and Mary (line 17) confirm when Isabel asks if they now understand.

In terms of the participants' positional framing in this setting, we see that Isabel, as the expert on the designated topic, took the source position in this setting and her peers initially took the listener position. Mary's continuous search for an answer and the agitated atmosphere show the difficult position the students were in when the expert student Isabel was unable to provide the requested information. However, when Mary challenged Isabel's idea by presenting an alternative idea, Mary took on a potential source position. This left the group with two potential sources: one arguing for the assumption that the pores in

TABLE 5
Excerpt 2b

1. Isabel	Low U-factor [*heat transfer coefficient*] is like, uhm::: that you don't emit so much air [. . . .]
2. Isabel	The air is not supposed to go through, because then the air comes from the outside and in, right? When heavy wind hits the house, it is supposed to, uhm::: the material will stop it. Because that is the reason why it's got many small air uhm::: air holes, right?
3. Mary	Yes, but isn't that like--
4. Isabel	So that it stops.
5. Mary	Yes, it stops, but isn't it like the air in a way meets that insulation, so that the insulation heats up the air that comes in?
6. Isabel	But the air--
7. Mary	And then it's releasing heat to the house, and then it's releasing the cold to like the outward layer of the house. Isn't it like that?
8. Isabel	No, like, if it's heavy wind, all of the air isn't entering the house. But some of it will enter the house.
9. Mary	It will hit the insulation, but the insulation makes it warm instead of cold?
10. Elise	What are we really talking about now?
11. Mary	I don't know. I don't get it. Like, how it happens, like how=
12. Isabel	Well, first the external wall stops most of the air, right, but then there are small- Like there are these tiny loopholes that perhaps only a tenth of it, or something, manages to pass through. And then there is the plastic, right, and then that, what's it called, the insulation material that stops everything. Right?
13. Elise	Si si [*said with Italian accent*]
14. Isabel	And then inside the house you have the ventilation system that circulates the air inside the house. There will always be some draft, right. But mostly around the windows. And the air that passes through, or if you have a window slightly open, the ventilation system will circulate it around the house, right. And then it moves out, and new air enters. Right?
15. Malin	Yes
16. Isabel	Anything else? ((*giggles*))
17. Mary	No. I got it now
18. Isabel	Okay. Good ((*The students start working on the next task*))

insulation prevent some of the wind from penetrating the insulation and the other arguing for the assumption that insulation transforms cold air into warm air when the air enters the insulation.

These ways of explaining insulation have been documented in several studies that have focused on students' common intuitive ideas (Chu, Treagust, Yeo, & Zadnik, 2012; Clark, 2006; Schnittca & Bell, 2011). In the current study, both versions in the end remained unchallenged. Instead, the group ended up confirming that they accepted Isabel's version. However, their confirmation does not necessarily mean that the students agreed or understood. Their consent might well have expressed that the students wanted to bring the unsettled issue to an end and that they acknowledged the designated expert as the source. Either way, the students ended up settling for a version inconsistent with the scientific conceptions held by experts in the field.

The second analytical point concerns the participants' conceptual framing (i.e., the way in which the participants organize information by bringing it in the foreground or background of their attention). When asked to elaborate on the heat transfer coefficient, a question that is positioned within formula framing, Isabel responded by providing a phenomenon description of wind hitting the insulation (phenomenon framing). Isabel could have responded to the question without repositioning the conceptual framing, for instance by elaborating on how to make calculations using the heat transfer coefficient. However, she chose not to invoke a formula framing. The reason for her choice might be found in the previous analysis of the participants' interaction in the expert group setting (Excerpt 1). This analysis showed that Isabel grappled with understanding how to make calculations using the heat transfer coefficient, and instead focused on something that she found easier to understand and explain to her peers.

Setting 3b: Working With the Heat Loss Simulation Tool. The group has just started calculating the heat loss of their house using the simulation tool. The students have changed several parameters to see the consequences for their house. When the teacher enters the room, the students have still not commented on any changes in output factors in the simulation. Malin seizes the opportunity to ask the teacher how to operate the simulation tool.

In the opening of Excerpt 3b (see Table 6), Malin asks the teacher what they are supposed to do with the simulation (line 1). The teacher takes the mouse cursor and explains in detail how to operate the simulation. Without explaining the term, he tells the students that they are to calculate the heat transfer coefficient of the construction material in their house (lines 2 and 4). At this point, Malin seizes the opportunity to ask the teacher what the heat transfer coefficient is (line 5). Instead of answering the question, the teacher bounces the question over to Isabel, the designated expert on this topic. Isabel replies by providing a definition of heat transfer coefficient (line 7). Malin follows up by asking what value is considered high for a heat transfer coefficient (line 8). Not picking up on Malin's request about the value, Isabel responds by going into the consequences of a high heat transfer coefficient (line 9). Not getting the answer she was looking for, Malin reframes her question. The tone in her voice along with bursting out the imperative "Numbers" shows that she is getting frustrated (line 10).

The conversation continues with a few more similar turns (lines 11–14). Isabel does not provide the information Malin is looking for until Malin asks Isabel a yes-and-no-question, and she confirms that 1 is a high value (line 14). Isabel adds that 0.3 or 0.13 is considered to be very good. The last part of Isabel's reply is formulated as a question addressed to the teacher, and her use of the past tense ("wasn't it?") indicates that she is referring to something they have talked about before, probably in the expert group setting. Instead of confirming Isabel's answer, the teacher encourages the students to look up the values on a Web page made available to them in the SCY-Lab (line 18). However, the students seem to have received the information they needed since they do not look up the links but continue working with the simulation.

In the context of van de Sande and Greeno's perspectival framing, three analytical points can be highlighted. In terms of the participants' positional framing, Malin's way of directing her question directly to the teacher shows that she invoked him as a possible source in this setting. The teacher, however, refrained from taking the source position and handed the question to Isabel, the designated expert student, by invoking her as a possible source. Isabel, accepting the appointed source position, tried to come up with a reasonable answer to Malin's question. The challenge appeared when Isabel did not

TABLE 6
Excerpt 3b

1.	Malin	What are we supposed to do?
2.	Teacher	Here you can find out how much energy the house uses. And then you choose for each (.) building element. Here are the walls ((*points with the mouse cursor at the relevant tab*)). And then you can choose-- What should the walls be made of?
3.	Malin	U::hum
4.	Teacher	Structure, that means what they are made of-- So you've got walls of wood, walls of concrete-- [. . .] And, then you have the total U-factor [heat transfer coefficient] for the walls here. ((*Points with the mouse cursor to the calculated value for the U-factor for the walls in the simulation*))
5.	Malin	What is the U-factor?
6.	Teacher	The U-factor? Isabel learned quite a bit about that. What is the U-factor? ((*looking at Isabel*))
7.	Isabel	U::hm That's the unit of measurement for how much heat loss there is in the house per square meter
8.	Malin	What is a high U-factor then? ((*looks at Isabel*))
9.	Isabel	That is not good. Because then the house emits--
10.	Malin	Yes, but what is it? How high is it then?
11.	Isabel	Then the house emits much heat--
12.	Malin	<u>Number!</u>
13.	Isabel	Then it gets cold more easily, and you need to heat it all the time.
14.	Malin	But, is like 1 a lot?
15.	Isabel	Yes
16.	Malin	That is a lot.
17.	Isabel	What was it again? 0.3 was really good. That was a super window, wasn't it? No, 0.13 ((*looks at the teacher*))
18.	Teacher	If you are to-- If you find one of those links, then they are written there.
19.	Elise	Isn't it good that it is- We are not supposed to lose so much heat, or lose so much this? ((*changes a parameter so that the bar showing heat loss in the diagram increases and points at the increasing bar*))
20.	Teacher	No, the U-factor should be low ((*The students carry on their work with the simulation*))

provide the information Malin was looking for and Malin became frustrated as a result. This mismatch between the information requested by Malin and the information provided by Isabel can better be understood as a lack of alignment in the students' conceptual framings (i.e., to what extent do participants achieve a mutual understanding of how to organize information when solving the task). Malin wanted to know the specific value for a high heat transfer coefficient, implying that she foregrounded the formula framing. Isabel, however, answered the question descriptively and focused on why it is desirable to have a high heat transfer coefficient, and in so doing foregrounded the phenomenon framing. Put differently, the students' divergence was caused by an observed but unaddressed lack of alignment in their conceptual framing. This challenge was settled when in the end Isabel provided the information Malin requested, implying that Isabel aligned her conceptual framing with Malin's. However, the two possible ways of framing the concept of heat remained unaddressed and implicit.

The final analytical point concerns the teacher's positional framing. By refraining from taking the source position, as he also did when interacting with Amanda and her basic group peers, the teacher found himself in the middle, positioned as neither a source nor a listener.

As seen before, the teacher faced the challenge of balancing the risk of undermining the expert student's role as the designated source against providing students with information that would help them to continue with their task on their own. The teacher's solution in the current situation was to recommend that Isabel and her peers look for the information on the Internet.

Regarding Isabel's and her peer group's conceptual framings during their presentations at the end of the project, although Isabel's group argued for their choices of materials based on heat loss, they did not explicitly use the concept of heat transfer coefficient during their presentation. This omission may indicate either that the students in this group did not consider the concept particularly relevant for communicating their choices or that they were unsure how to account for the meaning of the concept and therefore avoided mentioning it. Nevertheless, this implies that the phenomenon framing was maintained in the foreground of Isabel's and her peers' presentation, whereas the formula framing was the background, or more or less left out entirely.

DISCUSSION

The overall aim of this study was to provide deeper insight into the complexity of supporting students' development of conceptual understanding in collaborative learning settings. In the following sections, we first discuss the central empirical findings from the analyses of the student–teacher interactions and then discuss the empirical findings in relation to previous research findings.

Our analytical approach used van de Sande and Greeno's (2012) conceptualization of perspectival framing to investigate the participants' interactions. This method directed our analytical attention on what is referred to as the participants' positional framing (i.e., how participants relate to each other in interaction, as source and listener) as well as their ongoing work with constructing and making sense of coexisting conceptual framings (i.e., in what ways the students organize information or how they approach a concept from different perspectives). This analytical approach revealed four major concerns the teacher encountered and had to deal with as he facilitated the students' learning processes.

One concern encountered by the teacher was *directing the students' attention to coexisting conceptual perspectives*. The analyses show how the teacher continuously tried to ensure that the students considered the two conceptual framings, phenomenon framing and formula framing. This balancing activity was observed in the expert group session (Excerpt 1) and the two basic group settings (Excerpts 2a and 3b). Moreover, the analysis showed that the students tended to foreground the phenomenon framing and were more likely to background, or even exclude, the formula framing. We hypothesize that the main reason for the teacher's continuous effort to balance the two framings was that he perceived that the students struggled to explain heat loss within the formula framing, and thus saw that he had to provide additional support in the form of directing the students' attention and discussion toward this more complex issue.

The second concern encountered by the teacher was *creating a balance between providing the requested information versus supporting students in utilizing each other's knowledge and understanding.* The interaction analyses show that the teacher used two positioning strategies. One strategy was to take the source position, implying that he provided the information the students requested and needed. The teacher used this strategy in the expert group session (Excerpt 1). The second positioning strategy was refraining from taking the source position combined with designating other potential sources. This strategy was mainly used in the basic group settings in which the teacher tended to respond to the students' queries by invoking the designated expert students and bouncing the questions over to them (Excerpts 3a and 3b). In cases where he discovered that the expert student was incapable of providing the requested information, he invoked other potential sources, such as the designated Web resources. This implies that the teacher adjusted his positional framing strategy depending on the setting. He willingly took the source position within the expert group setting, whereas he refrained from the same position in the basic group settings.

So, how can the teacher's choice of the two positional framing strategies be explained? We argue that the teacher's choices of strategies must be seen in relation to the jigsaw design. This instructional design required that all students be given roles as experts and novices, i.e., intended source and listener positions. Being in the source position was challenging for the students, but being in the listener position was also challenging, since the students found it hard to challenge or ask for elaborations of the explanations provided by the expert students, i.e., the designated source (Excerpts 3a, 2b, and 3b). The teacher's decision to refrain from taking the source position in the basic group settings can be seen as a way of supporting the student in the expert position, and also a way of sustaining the main intention of the instructional design: to facilitate shared understanding by means of conceptual input from all students in their roles as experts and novices. This demonstrates the challenge that the teacher faced in balancing his positional framing. By taking the source position in the basic group setting, he risked undermining the students' exercise of their designated roles as experts. However, by refraining from taking the source position, he put himself in a position where he became incapable of knowing what the students did and did not understand.

The third concern encountered by the teacher was *balancing individual and group support*. This challenge was especially prominent in the expert group setting (Excerpt 1). Here, the teacher's attention was mainly directed toward responding to one student's queries and inferences, causing the other students to withdraw from being constructive listeners, i.e., refraining from engaging in an effort to achieve mutual understanding. This implies that the teacher seemed to provide sufficient and productive support to one individual student, but at the same time missed out on the opportunity to provide support that benefitted all the students in the group. Furthermore, the analyses show that the teacher tended to prompt the students to state, but not to display, their understanding (Excerpts 1 and 2a). This implies that the teacher did not know whether the group or the individual group members had achieved a sufficient understanding of the concept in focus or whether the students held intuitive ideas, as was the case in one of the student groups.

The fourth concern encountered by the teacher was *enabling the students see the relevance of the simulation*. In the empirical setting, the students engaged with a simulation tool designed to support their understanding of making calculations using the heat transfer coefficient (Excerpts 3a and 3b). The analyses of the participants' interaction while they engaged with the tool demonstrate the considerable interpretative effort needed for the students to make sense on different levels: making sense of what to do with the simulation (Excerpt 3b), understanding the term heat transfer coefficient as well as its relative value (Excerpts 3a and 3b), and seeing the relevance of the heat transfer coefficient in a broader sense. The simulation tool apparently did not provide enough conceptual support for the students to achieve a mutual understanding of the concept of heat transfer coefficient, since both groups summoned the teacher. In this sense, the teacher became an important resource in this setting by explaining instructions and directing students toward supplementary sources, as well as working with the students' conceptual ideas of the heat transfer coefficient.

The empirical findings of the current study confirm, as well as supplement, findings from previous research that have focused on student learning in computer-supported collaborative settings. This study provides deeper insight into peer interaction in these types of settings. Previous studies have documented productive aspects of peer collaboration: for example, it can foster learning-promoting talk and interaction among students (cf. Howe et al., 2007; Stahl, 2006). However, studies have also shown the challenging aspects of peer collaboration—for instance, that students rarely engage in discussions characterized by "constructive listening" (van de Sande & Greeno, 2012) or "exploratory talk" (Mercer, 2004), and that collaboration as an activity is difficult for students (Furberg & Arnseth, 2009). Our analyses show how these types of settings open up possibilities for peer-driven elicitation of intuitive ideas and attempts to develop mutual conceptual understanding. However, the analyses also demonstrate the significance of an intervention by a teacher who explicates coexisting intuitive ideas and scientific ideas, as well as settling potential conceptual disagreements. In addition, the analyses show the challenging aspects of peer collaboration and the importance of regulative support provided by the teacher to ensure that all students get a chance to provide their understanding. This support also includes elicitation of students' intuitive ideas or misconceptions.

Turning the focus to the instructional design, several studies have scrutinized the productive effects on students' construction and sharing of scientific arguments within settings based on various jigsaw designs (Aronson et al., 1978; Brown et al., 1993; Karacop & Doymus, 2013). Nevertheless, studies have also reported on more modest, or even negative, effects of jigsaw designs (Hänze & Berger, 2007; Souvignier & Kronenberger, 2007; Zacharia et al., 2011). Regarding the jigsaw design, the current study yielded differing findings. On the productive side, the jigsaw design supported an environment that urged ongoing, conceptually oriented peer discussions and elicitation of ideas. A challenging aspect of the jigsaw design, however, is the variations in the students' conceptual framing (what aspects of heat the students chose to focus on), the students' conceptual understanding, and the quality and accuracy of the explanations provided by the expert students. The peer interaction analyses show that these variations had a huge impact on the conceptually oriented discussions in the basic groups. Furthermore, the analyses show that even if an expert student had developed an understanding of a concept or was capable of providing a sophisticated explanation of the concept at issue, this did not ensure that mutual understanding developed in the peer group. Another challenging aspect of the jigsaw design is related to the participants' designated positions as sources and listeners. The instructional design with its designated positions was challenging for the teacher as well; for instance, the teacher sometimes needed to refrain from taking on the source position when the students obviously grappled with understanding the concepts at issue to avoid undermining the students' designated roles as experts.

Several studies have reported positive effects on students' learning related to the use of digital simulations (Rutten et al., 2012; Smetana & Bell, 2012). The analyses in the present study demonstrated productive sides of the students' use of the heat loss simulation tool; for instance, it prompted conceptually oriented talk in both groups related to unpacking the heat transfer coefficient. The simulation also became a tool for the teacher in that it actualized and supported his emphasis on the importance of understanding heat not only within phenomenon framing but also within formula framing. However, the analyses also show the considerable interpretive effort needed for students to make sense of the concepts embedded in the digital representations, in this case the concept of heat transfer coefficient. This finding coincides with previous process-oriented studies that focused on how digital representations are invoked and made sense of by students in collaborative learning settings (Furberg et al., 2013). Most importantly, the study shows the significance of teacher intervention in elaborating, explaining, and contextualizing the concepts and scientific principles embedded within digital resources. This interpretive support is important for students' development of conceptual understanding; it also shows the potential of digital support resources in prompting conceptually oriented teacher–student talk.

We began by drawing attention to a characteristic feature of the undertaken research within the field of CSCL: The analytical focus favors the impact of one or sometimes two support aspects. The core argument forming the basis for the current study was the importance of applying an ecological perspective: seeing students' learning processes as intertwined with support provided by a teacher, peer collaboration, instructional design, and their engagement with digital resources in use. To explore the "intertwinedness" and the concerns encountered by the teacher in these types of settings, we have argued for, and demonstrated, the relevance of opening up these classroom practices by means of interaction analysis (Furberg et al., 2013; Jordan & Henderson, 1995). Furthermore, we have argued for the significance of an analytical attention on *interaction trajectories*, which implies following interactions over time, across settings and between students groups (Ludvigsen et al., 2011). The main finding of the current study is that teacher interventions are crucial in supporting students' development of conceptual understanding. The teacher's intervention constitutes the "glue" in the setting by providing support in the intersection of peer collaboration, digital resources, and instructional design; when something goes awry in the intersection of these various forms of support, the teacher becomes the last layer of support.

Concluding Remarks

Facilitating students' development of conceptual understanding in CSCL settings is not a trivial task for teachers. Students' capabilities to participate critically, but constructively, in peer discussions, elicit and explore each other's intuitive ideas and scientific thinking, and settle disagreements are skills that needed to be cultivated over time. Research has shown the value of training students to participate in scientific discourse combined with introducing discussion ground rules (Howe et al., 2000; Mercer, 2004). To support this development, however, teachers must prioritize spending time and effort cultivating a classroom climate that supports critical, but constructive, exchanges of views, knowledge, and shared conceptual sense making. The current study demonstrates the necessity for teachers to critically scrutinize the productive as well as challenging aspects of any instructional design in relation to how the instructional design supports, or even prevents, productive learning processes. Overall, the findings from the current study show, more than anything, the complexity involved when designing computer-supported learning settings. We argue that teachers will benefit both from being aware of this complexity and from seeing themselves as facilitators of students' learning processes as they take place in the intersection of peer collaboration, digital support tools, and teacher intervention.

As a concluding remark, we will point out that several authors have emphasized the need for studies that address the role of the teacher and also the instructional setting in relation to students' use of computer simulations (Rasmussen & Ludvigsen, 2010; Smetana & Bell, 2012). Although the current study provides a contribution, further studies are needed in these areas. Specifically, studies that focus on different science domains, digital resources, and instructional designs are needed to understand the complexity of students' conceptual sense making in naturalistic CSCL settings.

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