Supporting students’ conceptual sense-making in computer-based settings in science

Exploring the support aspects of digital tools, peer collaboration, teacher intervention, and instructional design

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PhD Thesis

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Part I

Extended Abstract
1 Introduction

I will begin my thesis with a short narrative: In 2000/2001, I was attending a teacher-training program at the University of Oslo, where, by accident, I stumbled into a penal debate about e-learning organized by the Faculty of Education. The newest buzzword was e-learning, and the discussion in the panel debate was oriented toward how e-learning would revolutionize education. However, one of the participants in the debate asked an interesting question: “How does e-learning differ from other types of learning?” The other participants did not answer his question directly, but instead went on to discuss all the opportunities that e-learning would create. The questioner was obviously not satisfied with the other participants’ answers, and he asked his question again. In fact, from time to time during the debate, he kept going back to the exact same question about what e-learning really is, and none of the participants were able to give a satisfactory answer.

The reason I tell this story is that I can remember thinking that the question about e-learning was quite relevant, and I continued to ponder it over the time that followed. In fact, this question was essential in triggering my interest in finding out more about students’ learning processes when using computers—and, hence, it shaped the agendas for both my master thesis and the current doctoral thesis. Thus, my master thesis also served as a backdrop for the current PhD thesis. In my master thesis, I explored students’ learning from animations versus static visualizations in the field of genetics from a cognitive perspective. The study was conducted within the Viten.no research program1. Based on pre- and post-test results, I concluded that animations were superior to static visualizations, and based on interviews, I concluded that students found animations more motivating, “easier” to understand, and “easier” to remember than static representations, due to the movements in the representations. Hence, in my master thesis, I investigated a technological feature unique to computers that may support student learning.

Compared to my master thesis, the current thesis takes a broader approach in attempting to understand the best way to support students’ collaborative work with science concepts in computer-based settings. In these settings, students are often instructed to work collaboratively to try to make sense of the science content embedded in a computer-based learning environment. Working in pairs or in groups, the students are expected to support one

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1 The Viten.no research program is an ongoing design-based research project focused on designing a computer-based learning environment (Viten.no) for use in science subjects in Norwegian schools. See www.viten.no.
another’s learning processes while collaborating on solving specific tasks. Meanwhile, the teacher often circulates among the groups to support the students’ development of conceptual understanding. However, the role of the teacher is also to organize students’ activities in class, and the way in which a teacher plans for and organizes students’ activities (here termed “instructional design”) may support students’ learning processes. Hence, many computer-based settings can be described as complex settings, in which several support aspects—such as digital tools, peer collaboration, teacher interventions, and instructional design—are simultaneously in play. In order to enhance students’ learning from computer-based learning environments in science, it is important to understand how students work in these complex settings.

The current thesis studies the support for students’ conceptual sense-making in the context of collaborative work in computer-based settings from a socio-cultural perspective (Mortimer & Scott, 2003; Säljö, 2010; Vygotsky, 1978; Wertsch, 1991). This implies that learning is seen as a social and cognitive sense-making process among students, teachers, and resources at hand. This theoretical approach enables a focus on the multiple support aspects described above, since the approach allows learning to be investigated through a focus on students’ interactions, which take place at the intersection of these support aspects. However, in the field of science education, numerous studies have investigated learning seen as conceptual change. Research on conceptual change has been dominated primarily by a cognitive view on learning, which focuses on students’ cognitive processes and outcomes (diSessa, 2006; Mercer, 2008; Treagust & Duit, 2008). Although I acknowledge the important findings of these studies, I will also, in line with Mercer (2008), argue that we need more studies focusing on students’ conversations in naturalistic settings from a socio-cultural perspective. This implies trying to understand the process of conceptual development: that is, the development of understanding as an interactional achievement. I view learning as a process that takes place over time, and I make use of the process-oriented concept “conceptual sense-making” (Furberg, Kluge, & Ludvigsen, 2013) when referring to students’ work with science concepts. This concept will be elaborated on in section 2 (Theoretical Perspectives). Moreover, the majority of research on students’ learning in science when using computers has been conducted within either experimental or quasi-experimental setting (Donnelly, Linn, & Ludvigsen, 2014). To further expand our understanding of students’ learning when using computers, I will argue for the importance of studying students’ learning as it takes place in naturalistic settings. This approach also allows the consideration of the institutional aspect of
schooling when trying understanding students’ learning processes. Based on this theoretical perspective—that is, the socio-cultural perspective—the current thesis focuses on students’ conceptual sense-making in computer-based settings in the science classroom. Specifically, it focuses on students’ interactions as they take place at the intersection of digital tools, peer collaboration, teacher intervention, and instructional design. The combined focus on the interactional aspect and on students’ work with science concepts implies that the thesis focuses on both social and cognitive processes in the domain of science.

1.1 Choosing the computer-based learning environments Viten.no and SCY-Lab

In this section, I will provide a short description of two computer-based learning environments, which were chosen to investigate how to support students’ conceptual sense-making in computer-based settings. These environments are Viten.no and SCY-Lab. I will also provide a rationale for choosing these two learning environments for investigation.

The current thesis includes three studies, which are based on data collected through two research projects: the Viten.no project and the SCY (Science Created by You) project. The Viten.no project (Jorde, Strømme, Sørborg, Erlien, & Mork, 2003; Mork, 2011) is an ongoing design-based research project focused on designing a computer-based learning environment (Viten.no) for use in science subjects in Norwegian schools. The target group is students in lower and upper secondary school, and the Viten.no units consist of science information embedded in text, videos, pictures, static visualizations, simulations, open-ended tasks, and interactive tasks. A unique feature of Viten.no is its pedagogically designed animations, which represent scientific models. These can be described as the main pillars of the environment. Several of the units contain final consolidation activities, such as writing a newspaper article or participating in a role-play debate. The students are encouraged to collaborate in pairs when moving through the science content step by step.

The SCY project (de Jong et al., 2010) is a European design-based research project focused on developing a computer-based learning environment for science called SCY-Lab. The target group is students in lower and upper secondary school. In SCY-Lab, students collaborate in solving science-based assignments. In order to solve the assignments, students make use of knowledge from different disciplines, such as mathematics, physics, biology, or engineering. Although SCY-Lab consists of some text-based science information, it primarily
consists of different types of tools, such as a computer simulation, a mind-map tool, and a drawing tool. Students are expected to use these tools to solve science activities as part of the process of solving an overall assignment. The main goal of SCY-Lab is, therefore, to facilitate students’ work in solving an overall assignment.

In general, Viten.no and SCY-Lab are two high-quality computer-based learning environments that support students’ learning processes in science. Viten.no is well-known among Norwegian science teachers, and it is the most widely used computer-based learning environment in science in Norwegian schools. It is, therefore, highly relevant to study students’ work with this computer environment. SCY-Lab, on the other hand, is interesting to explore because it is the product of a large-scale collaborative research project involving different European countries. SCY-Lab also contains different technological features than Viten.no. However, the rationale for focusing on students’ conceptual sense-making in both Viten.no and SCY-Lab is related to both their similarities and their differences. The two learning environments are both high-quality environments in science that are based on social approaches to learning. However, the two learning environments employ different digital tools and are based on different pedagogical ideas. Specifically, in Viten.no, the idea is that students’ conceptual understanding will develop along a carefully designed, step-by-step menu as the students collaborate on making sense of science content. The step-by-step menu is designed according to design principles based on a clear progression in content difficulty. However, the idea is also that students’ conceptual understanding will develop as the students move back and forth in the menu to search for and discuss the science content needed to solve a final consolidation activity. In SCY-Lab, in contrast, the idea is that students’ conceptual understanding develop hand-in-hand with their collaborative use of tools—and, thus, with the creation and refinement of student products (here termed “emerging learning objects” (ELOs)) created by the tools. These differences between Viten.no and SCY-Lab enable me to explore how students work when using different types of computer-based learning environments, as well as to broaden my perspective of how different types of learning environments can support students’ conceptual understanding in science.
1.2 Overarching Aim

The overarching aim of this thesis is two-fold:

To gain knowledge about students’ conceptual sense-making in science during work in computer-based settings.

To explore how support in the form of digital tools, peer collaboration, instructional design, and teacher intervention can benefit students’ conceptual sense-making.

The overarching aim involves a focus on both social and cognitive processes of students’ learning in the domain of science as it takes place in naturalistic settings. The aim of the thesis is not to investigate how students understand science content per se, but to investigate how students work in computer-based settings and to determine how best to support students’ learning processes in the domain of science as it takes place in social settings. When students work in computer-based settings, different types of support may enhance their conceptual understanding in science. In the current thesis, I have chosen to focus on the support aspects of digital tools, peer collaboration, teacher intervention, and instructional design. In the thesis, I argue for the value of focusing on multiple support aspects, and I further argue that this multiple focus will enhance our understanding of students’ work with computer-based learning environments. Each of the studies constituting the empirical grounding of the current thesis addresses the overarching aim, although they do so in different manners. The four support aspects of digital tools, peer collaboration, teacher intervention, and instructional design are all present in the empirical settings of all three studies; however, the analytical attention is not directed to all of these aspects in all three studies. In the following, I will provide an overview of which aspects are prominent in the different studies and will discuss how the three studies fit into the overarching aim of the current thesis.

Study I investigates how animations—as compared to static visualizations—can support students’ conceptual sense-making in science (see Table 1). Specifically, this comparative study focuses on how students make sense of protein synthesis while interacting with two different types of representations. One class worked on a unit in a computer-based learning environment that contained animations, and another class worked on the same unit, but in an environment in which all the animations were replaced by static visualizations. The
study focuses on how the interaction between the students and the animation/static visualization—as well as the interactions among the students themselves—supports the students’ understanding of protein synthesis. Study I has a strong analytical focus on the domain of science, since it focuses on students’ development of conceptual understanding of the concept of protein synthesis. The study contributes to the overarching aim of the thesis by focusing on the support aspects of peer collaboration and digital tools (i.e., animation).

Study II investigates how students work with science content by focusing on how computer simulations may support students’ conceptual sense-making (see Table 2). In particular, this study investigates a new pedagogical and technological design that allows students to compare and contrast their own simulation results with peer-created simulation results—while, in the process, refining their own simulation results. The study focuses on students’ interactions as they work with a computer simulation on heat loss from low-energy buildings, and it proposes a model illustrating how pedagogical and technological design can create new learning opportunities for students. Although the empirical data display students’ conceptual sense-making of the heat-transfer coefficient, the analytical attention does not specifically focus on how students develop their understanding of the concept of the heat-transfer coefficient. Rather, Study II contributes to the overarching aim of the thesis by focusing on the support aspects of digital tools (i.e., simulation), peer collaboration, and instructional design (i.e., the compare and contrast activity).

Study III investigates the role of the teacher in a naturalistic classroom setting where students engage with computer-based science activities. In most science classrooms where different digital tools and learning environments are used, the teacher orchestrates the support aspects of the digital tools, initiates peer collaboration and creates an instructional design to facilitate students’ conceptual sense-making. In this case study, students’ work was structured by the jigsaw model, which implies organizing classroom activities in such a way that students within the same group become experts in different fields. The study follows students’ conceptual sense-making of the heat transfer coefficient over time. Nevertheless, the study does not focus on students’ conceptual development, per se. Rather, the study zooms out to focus on teacher interventions at the intersection of digital tools, peer collaboration, and instructional design (the jigsaw model). Hence, Study III contributes to the overarching aim of the thesis by focusing on all four support aspects simultaneously.
Table 1: Overview of each of the articles’ main aims and research questions (including a visual display of the support aspects targeted in each of the articles). The white areas in each of the figures display which support aspects are foregrounded in each of the studies—and hence, which support aspects are the subjects of the analytical focus. The grey areas display which support aspects are backgrounded in each of the studies.

<table>
<thead>
<tr>
<th>Study I: Animations versus static visualizations from a sociocultural perspective: A comparative study on students' sense-making of protein synthesis.</th>
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<td>- How do students make sense of an animation compared to a static visualization of protein synthesis?</td>
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<td>Support aspects: Peer collaboration and digital tools</td>
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<th>Study II: Students’ work with computer simulations: Contrasting peer-created simulation data creates extended learning opportunities.</th>
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<td>Research questions:</td>
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<td>- How do the students compare and contrast peer-created ELOs to refine their own ELO?</td>
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<td>- What learning opportunities are created as a result of examining peer-created ELOs?</td>
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<td>- How can we conceptualize the connection between social and cognitive processes in students’ sense-making?</td>
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<td>Support aspects: Peer collaboration, instructional design, and digital tools</td>
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<th>Study III: Exploring teacher intervention in the intersection of digital resources, peer collaboration, and instructional design.</th>
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<td>Main aim: To gain knowledge about the complex role of the teacher in supporting students’ conceptual sense-making when working in computer-based settings.</td>
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<td>- What concerns does the teacher encounter in student-teacher interactions when facilitating students’ development of conceptual understanding in CSCL settings?</td>
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<tr>
<td>Support aspects: Teacher intervention, peer collaboration, instructional design, and digital tools</td>
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1.3 Outline of thesis

The current thesis is organized into two parts: the extended abstract (Part I) and the three studies (Part II). The extended abstract comprises seven chapters, including this introductory chapter. The current section (Introduction) introduces the background and overarching aim of the current thesis, as well as describes how the three empirical studies contribute to the overarching aim of the thesis. In Section 2, Theoretical Perspectives, I begin by accounting for research on conceptual change, since this body of research has played a significant role in research on students’ conceptual learning in science over the last three to four decades (Treagust & Duit, 2008) and since two of my studies (Studies II and III) involve science topics that have primarily been investigated from a conceptual change perspective. I follow up by describing the socio-cultural stance taken in the current thesis, including the concepts of tools, mediational means, conceptual sense-making, and institutional aspects. Subsequently, I account for two metaphors for learning: the participation metaphor and the knowledge acquisition metaphor. I conclude the section with a theoretical discussion on how to connect social and cognitive processes. Here, I introduce van de Sande and Greeno’s (2012) framework on perspectival framing, which involves the concepts of conceptual framing, alignment of conceptual framing, positional framing, source, and listener. I have applied this framework in two of the studies in the current thesis: Studies II and III. In Section 3, Review of Relevant Research, I present studies addressing students’ learning in two specific science domains—genetics and thermal phenomenon. These are the two domains addressed in the student projects. I also present studies targeting aspects of support for students’ conceptual understanding, which connect with the overarching aim of the current thesis. Regarding the latter research area, I review studies related to the four support aspects presented above: digital tools, teacher intervention, peer collaboration, and instructional design. This review also accounts for the methods used in the majority of the studies within these fields. In Section 4, Empirical Context, I present the two computer-based learning environments (Viten and SCY-Lab) focused up on in the current thesis, as well as the empirical contexts of the three data collections. In Section 5, Methodology, I present the multiple methodological approaches used in the research, including the data corpuses and analytical procedures utilized in the three studies (Studies I, II, and III). I follow up by discussing the research credibility and ethical considerations of the thesis. In Section 6, Summary of the Studies, I present an overview of each of the three studies, before in Section 7, Discussion, accounting for the
contributions that the thesis makes to the field of supporting students’ conceptual sense-making in computer-based settings in science education.

Before describing my theoretical perspective, I will elaborate on some of the concepts used in the current thesis. In the current thesis, there exist variations among the three studies with regard to the use of concepts related to technology and learning settings. Specifically, the thesis uses the terms “computer-based learning environments” (Study I and II), “digital learning environments” (Study III), and “computer-supported collaborative learning settings” (Study III). The current extended abstract uses the terms “computer-based learning environments” and “computer-supported setting.” Note that this thesis does not distinguish theoretically between the terms “computer-based” and “computer-supported,” as these are seen as interchangeable. Another term used in this thesis that needs to be defined is “emerging learning object” (ELO). An ELO refers to a student product (e.g., simulation data) that may be refined over time. The assumption is that a series of learning opportunities emerges as students create and revise their products (de Jong et al., 2010). Learning opportunities refer to the processes through which students recap, reflect, problematize, and make sense of science concepts or scientific issues. Hence, students can refine their conceptual understanding along the iterative process of making revisions to their ELOs (de Jong et al., 2012; Kolodner et al., 2003). The terms “animation” and “simulation” are also central to the current thesis. An animation refers to a computer-based visualization that displays a continuous motion as it changes its structure over time (Plötzner & Lowe, 2012), and a simulation refers to a computer program that displays a model of a system or a process in which parameters can be manipulated (Rutten, van Joolingen, & van der Veen, 2012).
2 Theoretical Perspectives

In the field of science education, students’ conceptual understanding has traditionally been studied from the conceptual change point of view, which is primarily situated in the cognitive paradigm (Treagust & Duit, 2008). Students’ “conceptual understanding” in science refers to students’ understanding of science concepts. Further, “science concepts” refer to concepts that describe scientific phenomena or processes. It has been argued that, in order to enhance our understanding of students’ conceptual development, studies applying a perspective that also take into account social and cultural aspects of learning is of high value (Mercer, 2004; Roth, 2008; Wells, 2008). The current thesis is built on a socio-cultural perspective of learning and cognition, which implies that social and cognitive aspects of students’ learning processes are seen as intertwined (Leach & Scott, 2003; Säljö, 2010; Vygotsky, 1978; Wertsch, 1991).

Learning is seen as a social and cognitive sense-making process involving students, teachers, and resources at hand. Students’ learning is mediated by tools and by the institutional contexts that impact students’ learning processes. I will argue that, in order to understand students’ learning processes, these aspects need to be taken into account. In the following, I will first briefly account for the conceptual change perspective by presenting an overview of the two views that dominate the field: revolutionary theory and evolutionary theory. Second, I will describe the theoretical stance on which the current thesis is build: the socio-cultural stance. Third, I will account for two metaphors for learning—the participation metaphor and the knowledge acquisition metaphor—before I describe how social and cognitive processes can be conceptualized as intertwined processes.

2.1 Learning seen as conceptual change

Research on conceptual change has been dominated primarily by the cognitive view on learning (diSessa, 2006; Mercer, 2008; Treagust & Duit, 2008). From the cognitive perspective, learning is often conceptualized as knowledge acquisition, such that learning is seen as changes to students’ mental structures. Several such studies have focused on identifying students’ intuitive conceptions, explaining the nature of and changes in these conceptions in terms of cognitive theories, with the aim of improving the instructional design in order for students to reach conceptual change (diSessa, 2006). Intuitive conceptions are referred to through multiple terms (e.g., misconceptions, alternative conceptions, and
everyday conceptions) and they can be defined as students’ conceptions prior to instruction, which are at odds with the conceptions held by experts in the field. Intuitive conceptions are rooted in students’ everyday experiences, and students have good reasons to hold on to their intuitive conceptions, since these conceptions tend to work just fine in everyday contexts (e.g., in everyday communication and problem-solving). However, when students move from an everyday context to the context of science or science education, such intuitive conceptions are not judged as valid conceptions. According to Scott, Asoko, and Leach (2007), the teacher’s task is to show the students that scientific conceptions offer a new and powerful way of talking and thinking about the natural world.

There has long been a debate about how to conceptualize conceptual change. From this debate, two opposing theories have emerged, termed as revolutionary and evolutionary theory perspectives (Treagust & Duit, 2008). The revolutionary theory perspective (Vosniadou & Skpeliti, 2013) states that students hold relatively stable and coherent intuitive conceptions that resemble theories of conventional systems held by scientists, and that students, like scientists, hold on to their intuitive ideas unless they experience good reason to undergo conceptual change. However, when students are exposed to cognitive conflict in a particular science domain, they experience incommensurability between conceptual systems, which may lead the students to experience a radical shift from intuitive conceptions to scientific conceptions. The evolutionary theory perspective (diSessa, 2008), on the other hand, claims that students’ intuitive conceptions cannot be described as theory-like conception systems. Instead, students’ intuitive conceptions are fragmented and loosely connected; thus, they can be described as “knowledge-in-pieces” (ibid.). They are not stable entities, but instead may change according to context. Conceptual change should be viewed as a gradual process in which fragmented aspects of students’ intuitive conceptions can be used in the process of constructing scientific understanding.

Typically, studies on conceptual change targeting students’ mental structures are based on interviews, pre- and post-tests, and think-aloud protocols. They also often focus on students’ cognitive outcomes. Leach and Scott (2003) address the limitations in the conceptual change research and argue that research on conceptual change is useful for understanding why science is difficult to understand for many students. However, they also emphasize that this type of research does not provide insight into how students learn science in classrooms. Although I acknowledge the importance of studies on conceptual change, in line with Leach and Scott (2003) and Mercer (2008), I argue that, in order to understand the
process of students’ conceptual development in science, we need more studies focusing on students’ conversations as they take place in naturalistic settings. Specifically, I argue that the concept of conceptual change belongs to the cognitive paradigm and that the chosen concept of “conceptual sense-making” (as was introduced above) is more appropriate for the current thesis, which emphasizes the socio-cultural aspect of student learning.

2.2 Learning seen as conceptual sense-making

In the following, important aspects of the socio-cultural perspective are presented. Firstly, a conceptualization of learning as conceptual sense-making is accounted for. Subsequently, an outline of the central position of tools and mediation in the socio-cultural perspective is presented. Finally, the relevance of the institutional context in understanding students’ learning processes is presented.

2.2.1 Conceptual sense-making

As described above, the current thesis is built on a socio-cultural perspective of learning and cognition (Mortimer & Scott, 2003; Säljö, 2010; Vygotsky, 1978; Wertsch, 1991). According to this theoretical perspective, learning is seen as a social and cognitive sense-making process between students, teachers, and resources at hand. Social and cognitive aspects of students’ learning processes are considered to be intertwined, and the unit of analysis is social interaction. This view of learning implies that learning can be investigated by focusing on students’ interactions. Conversely, learning cannot be investigated by focusing on individual minds. As argued by Linell (1998), researchers do not have direct access to students’ individual minds; that is, “speakers do not speak out of their heads” (p. 94). This implies that we cannot understand students’ verbal behaviors unless we also have access to the social and cultural contexts to which the students’ discourse belongs. In other words, cognition cannot be studied independently of the social and cultural context in which a given learning activity is situated.

The current thesis uses the concept of conceptual sense-making (Furberg et al., 2013; Lemke, 1990; Linell, 1998; Vygotsky, 1986) when referring to the discourse of a participation activity. The term “conceptual sense-making” has previously been used by, among other, Furberg et al. (2013), in their study on students’ reasoning with representations in the field of science. Furberg et al. (2013) point out that “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 the scientific concept” (p.4). Building on this conceptualization of conceptual sense-making, I will, in the following, emphasize why this concept was chosen for the current thesis.

The concept of sense-making, as opposed to meaning-making, was chosen according to Vygotsky’s effort to distinguish between sense and meaning (Vygotsky, 1986; Wertsch, 1985). By meaning Vygotsky refers to the lexical meaning of a concept, which can be found in a dictionary. By “sense,” Vygotsky refers to the more local meaning that concepts and expressions take on in concrete participation activities. The term sense takes into account that concepts and expressions may have different meanings in different contexts. The lexical meaning of a concept only has a meaning potential, which becomes realized through local conversations. In order to acknowledge the fact that participants bring with them different prior knowledge and experiences about specific concepts, as well as that these concepts are to be socially negotiated in the local activity, I choose to use the term “sense-making” in the current thesis. In this sense, the term sense-making also suggests a social focus. However, I choose to add the term “conceptual” to sense-making because I focus on students’ work with science concepts and because the term conceptual displays a focus on cognition. Hence, the term “students’ conceptual sense-making” connects a focus on students’ cognition (in the domain of science) with a focus on social processes in student learning.

2.2.2 Tools and mediation

The concepts of tool and mediation are important in the socio-cultural perspective of learning (Säljö, 2010; Wertsch, 1998). These concepts are related to the view that social and cultural contexts are highly important in understanding students’ sense-making processes. Students’ sense-making is mediated by physical and psychological tools, which are part of the social and cultural context. This implies that trying to understand students’ conceptual sense-making involves understanding the mediational means—that is, the physical and psychological tools—involved in the activity (Wertsch, 1998). Directing the focus toward physical tools (e.g., a hammer, a pencil, or a digital device, such as a calculator), the most relevant tool for the current thesis is that of a computer. According to Säljö (2010), computers not only support learning, but also transform the way we learn. The computer consists of functionalities that enable: a) the storing of information and the creation of a social memory; b) access to this social memory; and c) performance of complex analytical processes (p. 56). These
functionalities transform learning in the sense that the computer merges with our cognitive abilities. “Knowing” does not only refer to the knowledge stored in people’s minds; it also encompasses the ability to handle and utilize the computer and other mediational tools. In the current thesis, I focus on two specific digital tools embedded in computer-supported learning environments. These are a computer simulation and an animation, each representing models of complex scientific phenomena and processes. I refer to these tools as “representations.” These representations had been designed by science experts, and they come with specific meaning potentials (Furberg et al., 2013; Linell, 1998). Hence, understanding representations involves trying to understand their inscribed meaning potentials. This may not always be a straightforward process, and coming to understand specific representations may involve negotiating different meaning potentials with the help of teacher or peers. Negotiating the cultural tool of representations may also involve working with the relationship between a set of science concepts embedded in the representation.

This leads us to the concept of “psychological tools,” which refers to the concepts and languages used in a sense-making process. Mediation is not only related to physical tools. For example, concepts and linguistic actions are mediating the world, and participants experience the world as meaningful through the use of language. Language as mediational means also enables specific types of interactions between participants, and it is also directly related to learning. According to Lemke (1990), learning science means learning how to talk in a specific way using the concepts of science. The language of science can be described as a “thematic pattern,” which is a “pattern of connections among the meaning of words in a particular field of science” (p. 12). Science concepts are never used in isolation; instead, their meanings are constituted in their interconnections. This involves combining science concepts in a meaningful way to reflect the acknowledged way of talking about science defined by experts in the field. Thus, one aim of teaching science is to evoke specific thematic patterns in students’ talk. Building on Lemke’s (1990) term thematic pattern, Scott, Mortimer, and Ametller (2011) create the term “conceptual link-making.” Conceptual link-making refers to students making meaningful links between science concepts, such that learning conceptual scientific knowledge involves coming to understand the interlinked systems that connect science concepts. The authors situate the term conceptual link-making in both constructivist- and socio-cultural perspectives on learning. They argue that basic assumptions in constructivism are that learning conceptual knowledge involves making links between prior knowledge and new ideas and that the process of internalization from the socio-cultural
The unique relationship that exist between the scientific concepts and its object … this relationship is characterized by the fact that it is mediated through other concepts. Consequently, in its relationship to the objects, the scientific concept includes a relationship to another concept, that is it includes the most basic element of a concept system.

Students’ use of concepts becomes articulated through language. In the current thesis, I focus on the content of conversations as it is displayed through language. However, although the content of a conversation may show that students try out new science concepts in a conversation, it does not necessarily mean that the students understand the full meaning of the concept (Haug & Ødegaard, 2014). Students’ first use of a concept may be a “parroting,” or simple repetition, of the teacher’s use of the concept. Wertsch (1998) points out that “development often occurs through using a cultural tool before (original italic) an agent fully understands what this cultural tool is or how it works” (p. 132). This implies that it might be important to evoke the thematic pattern of science in students’ discourse as a tool for coming to understand science. This also implies that, when we analyze the content in students’ conversations as it is displayed through language, it is important to be aware that students might still be in the process of understanding the scientific concepts they use.

2.2.3 The institutional aspect

According to the socio-cultural perspective, understanding students’ learning processes involves taking into account the institutional context in which learning processes take place. Formal learning is often situated within the institutional context of a school, and practices in schools are based on strong traditions that have been developed through hundreds of years of schooling. Traditionally, students’ development of conceptual understanding can be characterized as “top-down” development, to use Vygotsky’s (1998) term (see also Lemke, 1990). This means that the concepts are introduced in an abstract manner and that students seek to make sense of the abstract concepts by trying to make them relevant to specific contexts. These concepts are termed scientific concepts, and they have been defined and
systematized through a system that spans the course of history. In contrast, “bottom-up” conceptual development involves novices participating in an activity system other than schooling—and, through this participation, finding relevant ways to make sense of specific concepts. “Bottom-up” processing occurs, for example, in apprenticeship and in everyday experiences, and intuitive concepts are example of concepts generated through “bottom-up” processing. Intuitive concepts are not part of a systematized scientific vocabulary. However, in “top-down” activities, which take place in schools, specific structures for communication are developed (Säljö, 2000). This implies that linguistic structures, as well as norms and cultural routines, exist prior to students’ interactions in the culture of schooling (Linell, 1998). Students are expected to operate within these structures, which implies that students are expected to navigate within an institutional framing, trying to identify what the expected way to communicate is. Examples of such communications may include learning how to respond to different types of teacher questions, how to invoke the teacher’s attention in problem-solving activities, and how to respond to peers’ utterances in group discussions. Students also know that they are being assessed according to the demands set by a curriculum, which might impact their communication. Successful students are able to identify and adapt to the specific set of communicative structures and rules that constitute school as an institution. However, at the same time that students (and teachers) are adapting to structures, they are also modifying the structures (Säljö, 2000). According to Linell (1998: 60), “Social structures are (re)created, tried out, tested, negotiated and modified every time they are instantiated or drawn upon.” Thus, the institutional aspect of schooling is not a static entity, but is developing over time.

In addition to the institutional aspects of linguistic structures, norms, and cultural routines, the institutional aspect is also embedded in material artefacts, such as books and other types of learning resources (Furberg, 2009; Säljö, 2000). For the current thesis it is relevant to point out that the institutional aspect is also embedded in computer-based learning environments. Such digital environments are designed through an institutional assumption regarding how and what learning can be achieved. They may, therefore, be seen as products of the institutional aspect of schooling. Moreover, computer-based learning environments are designed to be used in an institutional praxis, within which teaching and learning are the main aims. Thus, computer-based learning environments may set the condition for learning. This implies that students’ sense-making also exists on an institutional level.

According to Linell (1998), linguistic structures, norms, and cultural routines exist prior to the interactions taking place at a specific moment in history; they are generated over a
longer timescale. However, these structures, norms and routines are drawn up on and reconstructed through interaction. In sum, students’ sense-making exists not only on an interactional level (situated interaction), but also on an institutional level (socio-cultural practices) that has developed over a longer time scale. In Study II, we argue that our discussion of the institutional impact on students’ sense-making is an extension and specification of the analytic stance on framing developed by van de Sande and Greeno (2012). The analytical framework of van de Sande and Greeno (2012) will be introduced below.

2.3 Drawing on two metaphors for learning: Participation and knowledge acquisition

In an influential article by Sfard (1998), the author highlights two powerful metaphors for learning: the participation metaphor and the knowledge acquisition metaphor. It can be argued that the participation metaphor belongs to the socio-cultural perspective, while the acquisition metaphor belongs to the cognitive perspective. However, Sfard (1998) does not argue for either of these metaphors, nor does she argue for merging the two perspectives on learning. Instead, she argues that “the most powerful research is the one that stands on more than one metaphorical leg” (Sfard, 1998: 11). Further, Sfard (1998) and Packer and Goicoechea (2000) argue that cognitive and socio-cultural views on learning build on different ontological assumptions: The cognitive perspective constitutes a dualist ontology, which views the student as independent from the world, while the socio-cultural perspective conceives of a non-dualist ontology, which views the student and the world as being mutually constructed and constituted by one another. Differences in the ontological assumptions of the two theoretical perspectives imply different epistemologies. Within the socio-cultural perspective, students’ learning cannot be investigated separately from the social and cultural context in which the learning takes place. This implies that students’ learning can be investigated by focusing on the social interactions situated in a naturalistic context. Within the cognitive perspective, students’ learning (i.e., their mental structures) is investigated by focusing on students’ understanding without differentiating the social and cultural context involved. Within this tradition, students’ learning is most often explored through pre- and post-tests, think-aloud protocols, and interviews. However, several researchers have argued for the importance of using multiple theoretical and methodological approaches when
investigating students’ learning of science concepts (Dolonen & Ludvigsen, 2012; Sfard, 1998; Treagust & Duit, 2008).

The formerly described metaphors serve as a backdrop for the conceptualization of learning in the current thesis. The thesis conceptualizes learning as conceptual sense-making, implying that the participation metaphor resonates with the term “sense-making” (i.e., learning seen as a social process taking place in social interaction. The acquisition metaphor, on the other hand, resonates with the term “conceptual” (i.e., a focus on how students develop an understanding of scientific concepts). Hence, conceptual sense-making indicates a dual focus on social processes (i.e., sense-making processes) and cognition (i.e., how students develop their understanding of scientific concepts). The underlying argument in this thesis is that both aspects are pivotal for understanding student learning. The analytical implication of this perspective is that the focus is on both the students’ individual understanding and on how their development of such understanding is part of and takes place in social interaction. In the next section, I will elaborate on how social and cognitive processes can be seen as intertwined.

2.4 Connecting social and cognitive processes

From the socio-cultural perspective on learning, social and cognitive processes are seen as intertwined (Saxe, de Kirby, Le, Sitabkhan, & Kang, 2015; Vygotsky, 1986; Wertsch, 1991). van de Sande and Greeno (2012) have proposed a set of analytical concepts on framing, which can be used to conceptualize the link between the individual and social aspects of the learning process. These concepts are: positional framing, source, listener, conceptual framing, and alignment of conceptual framing. “Positional framing” refers to how students relate to one another in interactions, particularly with regard to each student’s different contribution in the group’s activity. The term positional framing comprises the terms “source” and “listener.” A source refers to a person (here, a student) or physical resource that conveys information that another student needs in order to solve a task or understand the issue under investigation. A listener refers to a student who tries to interpret the source with the aim of achieving mutual understanding. A listener does not only refer to a person who is listening in the trivial sense of the word; its definition must be seen in relation to the definition of the source. That is, being a listener involves needing information from a source in order to solve a task or understand an issue under investigation. There is a gap between the listener and the source,
which needs to be closed in order to reach mutual understanding. In this context, the phrase “reach mutual understanding” can be seen as van de Sande and Greeno’s conceptualization of learning. Moreover, the term “conceptual framing” refers to how students organize information in activities. By using this concept, we can specify what aspects of information are in the foreground and background of participants’ attention. The term “alignment of conceptual framing” refers to the degree to which students have a mutual understanding of how to organize information in an activity. Thus, the alignment of conceptual framing is seen as a condition for achieving mutual understanding of a (science) content.

In Study II and Study III, we make use of these analytical concepts, and in Study II one of our research questions targets how to conceptualize the connection between social and cognitive processes in students’ sense-making. In this study, we elaborate on these concepts and discuss how the concepts of framing allow for an integrated view of social and cognitive processes in students’ conceptual sense-making, while simultaneously allowing for a differentiation between which students are contributing to interactional achievement in the social activity. Specifically, by applying the concepts of positional framing, source, and listener, we are able to show three distinct aspects of the intertwined relationships between social and cognitive processes that impact students’ learning. One aspect concerns how students participate in the conversation as individuals. The concepts of source and listener constitute tools for displaying how students, as individuals, take part in the interplay of interactions: that is, how the students alternate in providing and receiving information. These concepts also enable us to specify, moment for moment, which students contribute to the knowledge construction of other students. Another aspect is related to how the concept of a source links individuals to specific knowledge, since individual students contain specific knowledge that a group may need to develop a mutual understanding and proceed in solving a task. A third aspect is related to a second form of source: That is, the concept of a source may also refer to material resources, such as books or digital tools. This implies that the concept of a source makes it possible to analyze which knowledge students invoke in an interaction.
3 Review of Relevant Research

The three studies (Study I, II, and III) embedded in the current thesis target students’ work in the fields of genetics and thermal phenomena, and the particular concepts that students work with are protein synthesis and heat. Learning new concepts in the field of science is neither a trivial nor a straightforward matter. In fact, the reason I have chosen to focus on students’ work with the concepts of protein synthesis and heat is that these concepts are particularly difficult for students to grasp (Chu, Treagust, Yeo, & Zadnik, 2012; Gericke & Wahlberg, 2013). In order for students to develop a coherent scientific understanding of concepts in general of and these concepts in particular, students’ learning processes may require substantial educational support. Furthermore, it is of particular interest to study the interactional data of settings when students try to make sense of complex concepts, since these settings often imply discussions and negotiations of meaning. Analyzing data from these types of settings may provide insight into students’ learning processes, as well as into how different types of support facilitate these processes.

In the following, first, findings from studies targeting students’ learning in the fields of genetics and thermal phenomena are discussed, making it possible to identify the difficulties students encounter when learning about protein synthesis and heat. Second, studies targeting different supports for students’ conceptual understanding are presented. With regard to the second research area, the review focuses on studies related to the following support aspects: digital tools, peer collaboration, instructional design, and teacher interventions. I have chosen to review multiple areas in order to position my contribution, since my contribution is situated in the intersection of all of the reviewed areas. However, each of the mentioned areas and support aspects could have been subject to a review in itself; thus, my ambition is not to provide an exhaustive review for each area. The reviews are selective in relation to the three studies (Study I, II, and III) conducted as part of this thesis, and the aim of the reviews is to outline important studies within the four support aspects.
3.1 Research on students’ learning in specific science domains

3.1.1 Genetics

In Study III, the student project targets the science domain of protein synthesis. Several studies have pointed out the importance of teaching protein synthesis in order for students to understand the fundamental aspects of genetics (Duncan & Reiser, 2007; Lewis & Kattman, 2004; Marbach-Ad, 2001; Thörne & Gericke, 2014). Previous studies on student learning from protein synthesis have targeted how textbooks present the topic (Gericke, Hagberg, dos Santos, Joaquim, & El-Hani, 2014; Martínez-Gracia, Gil-Quilez, & Osada, 2006); how different types of representations affect students’ learning of protein synthesis (Marbach-Ad, Rotbain, & Stavy, 2008; Starbek, Starčič Erjavec, & Peklaj, 2010); how the topic is taught in school (Duncan & Tseng, 2011; Thörne & Gericke, 2014); and how students understand the role of the protein in the relationship between genes and traits (Lewis & Kattman, 2004; Marbach-Ad, 2001). Several studies have reported that molecular genetics is difficult both to learn and as to teach (Lewis & Wood-Robinson, 2000; Venville, Gribble, & Donovan, 2005; Williams, DeBarger, Montgomery, Zhou, & Tate, 2012). In particular, understanding protein synthesis is an intellectual challenge for students (Gericke & Wahlberg, 2013; Marbach-Ad, 2001; Marbach-Ad & Stavy, 2000; Starbek et al., 2010), since the concepts involved are abstract, and the process itself is remote from students’ everyday experiences. Hence, students are completely unfamiliar with protein synthesis prior to science instruction (Yarden & Yarden, 2010).

Studies demonstrate that students display considerable confusion and uncertainty when trying to explain genetics. Although studies claim that students seem to hold few intuitive conceptions in the field of genetics (Lewis & Wood-Robinson, 2000), Lewis and Kattmann (2004) found that students do hold an intuitive conception of genes as small trait-bearing particles. They report that this view may prevent the students from understanding the conceptual relationship between genes and traits, which is seen as essential for understanding genetics. As demonstrated by Marbach-Ad (2001), understanding the relationship between genes and traits is challenging. In her study, Marbach-Ad (2001) investigated, among others, how different educated groups understood the coding relationship (i.e., the function of RNA) between gene and trait. The study revealed that grade 9 students thought of genes as
inseparable from traits (an incorrect understanding); that grade 12 students and pre-service teachers thought of genes as determining traits (a partial understanding); and that pre-service teachers who had previously earned a degree thought of genes as coding for traits (a robust understanding). Marbach-Ad (2001) indicates that these results can be explained by the teaching methods used at the different educational levels. In line with the results of this study, several studies have demonstrated the importance of teaching protein synthesis as a means to understand the conceptual relationship between gene and trait (Duncan & Reiser, 2007; Lewis & Kattman, 2004; Marbach-Ad, 2001; Thörne & Gericke, 2014). The current review indicates that students may need considerable support in order to develop a scientific understanding of protein synthesis. In Study I, we target this challenge by demonstrating how students’ understanding of protein synthesis may be supported by means of digital tools, such as animations and static visualizations.

3.1.2 Heat

In Studies I and II, the student project targets the science domain of heat. Several studies have directed analytical attention toward students’ understanding of thermal-related concepts (e.g., Chu et al., 2012; Clark, 2006; Harrison, Grayson, & Treagust, 1999; Lewis & Linn, 1994; Schnittca & Bell, 2011). One reason for this is that heat is a complex scientific concept to understand, since students’ everyday understanding of the concept does not always match the concept’s scientific definition. Studies on students’ conceptions of heat belong primarily to the conceptual-change literature, as accounted for in the theoretical section. Findings from studies focusing on the nature of the intuitive conceptions of heat held by students show, for instance, that students believe that wool warms objects (Chu et al., 2012; Clark, 2006; Lewis & Linn, 1994), that air transmits heat and cold, and that materials with holes allow heat and cold to pass through (Clark, 2006). The latter belief is referred to as the “barrier model,” and it relates to students’ ontological understanding of heat as substances, rather than processes. According to Chi et al. (1994), a shift from an intuitive to a scientific conception may require a shift in students’ ontological understanding (see also Wiser & Amin, 2001).

A recent large-scale study conducted by Chu et al. (2012) investigated the understanding of students in grades 10, 11, and 12 regarding thermal concepts in everyday contexts by using questionnaires developed on the basis of research literature to determine students’ alternative conceptions in the field. One aim of the study was to investigate students’ understanding of thermal concepts in everyday contexts, both in general and across
three different variables that potentially influenced the students’ understanding of these concepts. The results show that the students’ years of schooling, the science subjects currently being studied, and the science subjects on thermal energy previously studied had an impact on students’ conceptual understanding. Although years of schooling seemed to influence students’ conceptual understanding, students at all age groups demonstrated difficulty applying scientific concepts to everyday contexts. This study is in line with other studies that claim that students’ intuitive beliefs are quite resistant to change (Laburu & Niaz, 2002; Lewis & Linn, 1994). Even students who have been exposed to teaching about heat energy for several years still believe in intuitive conceptions (Lewis & Linn, 1994). As pointed out by several researchers, the reason for this is that people experience no need in their everyday life to change their intuitive conceptions of heat, since these conceptions work quite well in explaining the thermal phenomena related to everyday experiences (e.g., in the case of the belief that heat is trapped inside an aluminum wrapped lunch packet) (Chu et al., 2012; Lewis & Linn, 1994). These results have made researchers aware of the importance of designing instruction that targets students’ intuitive conceptions of thermal phenomena in order to prevent these students from holding intuitive conceptions parallel to the conceptions taught in school (Lewis & Linn, 1994; Schnittca & Bell, 2011). Other studies have pointed out that providing enough instructional time is also important in order to obtain conceptual change (Clark & Linn, 2003; Harrison et al., 1999). Thus, in Study II (Strømme & Ludvigsen, in review) and Study III (Strømme & Furberg, 2015), we target students’ sense-making of thermal concepts, while, in Study III, students’ intuitive conceptions are part of the empirical grounding.

### 3.2 Research on support for students’ conceptual understanding

As demonstrated in the previous section (section 3.1, Research on students’ learning in specific science domains), students’ conceptual development in the fields of genetics and thermal phenomena may need substantial support. Research on students’ learning in computer-based settings has focused on different types of support, such as digital tools, peer collaboration, instructional design, and teacher interventions. In the following, I will review previous research related to these four support aspects. I will begin by reviewing studies on digital tools of simulations and animations.
### 3.2.1 Digital tools

An extensive body of research has focused on how digital tools may support students’ learning (Ainsworth & VanLabeke, 2004; Ploetzner & Lowe, 2012; Rutten et al., 2012). Relevant for the current thesis are research focusing on students’ use of the digital tools of simulations and animations. In the following, I will review studies on students’ use of computer simulations and students’ use of animations, since simulations and animations are the central tools used in the three studies (Study I, II, and III).

Several studies have demonstrated that students’ learning can be effectively supported by computer simulations (see Rutten et al., 2012; Smetana & Bell, 2012). Such simulations may support students’ development of conceptual understanding (e.g., Olympiou & Zacharias, 2013; Stern, Barnea, & Shauli, 2008; Trey & Khan, 2008), as well as students’ development of inquiry skills (e.g., Huppert, Lomask, & Lazarowitz, 2002; Klahr, Triona, & Williams, 2007; Lin & Lehman, 1999). There is a broad consensus among researchers that simulation is an effective tool for student learning in science; thus, the question is no longer whether simulations work, but, rather, how to optimize student learning from simulations (Rutten et al., 2012; Smetana & Bell, 2012). One stream of research on how to optimize student learning from simulations has focused on embedding different types of support, such as instructions, guidelines, and prompts, in computer simulations (Fund, 2007; Trey & Khan, 2008; van der Meij & de Jong, 2006). Studies belonging to this strain of research have demonstrated that students’ learning from simulations may be supported by embedding components that: 1) structure the main steps in the process of solving the problem (Fund, 2007), 2) encourage students to reflect on the process of solving the problem and monitoring comprehension (Eckhardt, Urhahne, Conrad, & Harms, 2013; Fund, 2007), or 3) allow students to work with multiple representations (van der Meij & de Jong, 2006). Another strain of research has focused on students’ collaborations when working with simulation tool (Dori & Belcher, 2005; Manlove, Lazonder, & de Jong, 2009; Sins, Savelsberg, van Jooleingen, & van Hout-Wolters, 2011). Studies indicate that collaboration has a positive impact on student learning outcomes (Manlove et al., 2009; Shieh, 2012); however, there also exist studies demonstrating that supporting student collaboration does not necessarily lead to improved learning outcomes (Saab, van Jooleingen, & van Hout-Wolters, 2007; Sins et al., 2011).

In a study belonging to the first strain of research—that is, how to optimize students’ learning by embedding different types of support into computer simulations—Lin and Lehman (1999) investigate the effect of embedding rule-based, emotion-focused, and reason-
justification prompts in the simulation environment on college biology students’ ability to solve problems. The results of the students’ problem-solving tests showed that reason-justification prompts enhanced the transfer of learning to new contexts. These results were supported by results from interviews, which demonstrated that the reason-justification prompts helped students critically reflect on experiment design strategies and principles—which, in turn, enhanced the transfer of learning to new contexts. Hence, this study on student learning from simulations reveals that embedding prompts into a simulation environment that encourage students to justify and analyze the consequences of their decisions is beneficial for students’ learning outcomes. The research design of this study is, however, typical of studies seeking to optimize students’ learning from computer simulations: That is, the study assigned different supports embedded in a technological design to different treatment groups. Nevertheless, the review studies of both Smethana and Bell (2012) and Rutten et al. (2012) suggest that future studies on students’ learning from computer simulations should address “the broader perspective” (e.g., the lesson scenario, the role of the teacher, the curriculum, and the instructional design), and what new “features” contribute to student learning.

In Study II (Strømme & Ludvigsen, in review), we target these recommendations for future research by focusing on students’ work through a new technological feature embedded in a computer simulation. This new technological design also allows a new pedagogical design, in which students critically examine peer-created simulation data with the purpose of refining their own simulation data. The majority of studies in this field are effect studies that investigate different types of interventions by means of pre- and post-test analyses of student learning outcomes. Moreover, the majority of these studies is conducted within cognitive or socio-cognitive frameworks and has not focused on the learning process of the activity in which the students engage. I will argue that Study II also constitutes a theoretical and methodological contribution to the field of students’ learning from computer simulations by focusing on social interaction as the unit of analysis.

Turning the focus to animations, students’ learning from animations versus static visualizations has been thoroughly investigated (see Höffler & Leutner, 2007; Ploetzner & Lowe, 2012). The majority of studies report animations being superior to static visualizations for student learning (e.g., Höffler & Leutner, 2007; Lin & Atkinson, 2011; Ryoo & Linn, 2012). However, there also exist studies showing zero or negative effects of animations versus static visualization (e.g., Kühl, Scheiter, Gerjets, & Gemballa, 2011; Mayer, Hegarty, Mayer, & Campbell, 2005). Fortunately, the results are more consistent in the domain of
protein synthesis, where a number of studies have demonstrated that animations are especially effective for learning molecular processes (e.g., protein synthesis), since such processes are dynamic and remote from students’ everyday experiences (Marbach-Ad et al., 2008; Yarden & Yarden, 2010). In addition to studies measuring students’ learning from animations versus static illustrations (e.g., Marbac-Ad et al., 2008; McClean et al., 2005), several studies have focused on specific support aspects that enable students to effectively benefit from animations (e.g., Clark & Mayer, 2011; de Koning, Tabbers, Rikers, & Paas, 2009). Regarding the latter type of studies, one strain of research has investigated students’ learning from segmented animations (animations presented in smaller chunks, with pauses in between) (see Spanjers, Van Gog, & van Merriënboer, 2010). These studies show that segmented animations are beneficial for students’ learning.

The current thesis focuses on an animation that is segmented. Thus, particularly relevant for the current thesis is an effect study conducted by Spanjers, van Gog, Wouters, and van Merriënboer (2012), who attempt to explain why segmented animations are beneficial for learning. Spanjers et al. (2012) investigated the following two hypotheses: 1) segmentation enables students to process each element in an animation before moving on to the next element, and 2) segmentation cues students about the animation structure by displaying which segments belong together and which segments should naturally be separated. Students were assigned to four conditions: non-segmented animations, animations segmented by pauses only, animations segmented by temporally darkening the screen only, and animations segmented by both pauses and temporally darkening the screen. Spanjers et al. (2012) concluded that both temporally cuing and pausing had positive effects on student learning. Their study can be situated within a cognitive framework, since the hypothesis on cuing and pausing is related to cognition and what is going on in an individual’s mind.

Another study that is particularly relevant for the current thesis is an effect study that targets students’ learning of protein synthesis by means of animations versus static visualizations. In the study of Marbach-Ad and her colleagues (2008), students were divided into three groups that received different treatments: an animation group, a static-visualization group, and a control group (in which students were taught in the traditional lecture format). Students’ understanding of protein synthesis were detected via pre- and post-tests and interviews. The open-ended questions in the test showed that the animation group performed significantly better than the static visualization group. A close inspection of the findings for subtopics in the pre- and post-tests reveals that there were no differences in performance
between the animation group and the static visualization group for questions targeting the structures of DNA and RNA. However, on open-ended questions targeting molecular processes, such as DNA replication, transcription, and translation, the animation group significantly outperformed the static visualization group. As mentioned above, several studies have proven that computer animations are particular effective for teaching processes, such as the process of protein synthesis (Marbac-Ad et al., 2008; McClean et al., 2005; O’Day, 2006; Starbek et al., 2010).

In Study I (Strømme & Mork, in review) we target student learning of protein synthesis by means of animations versus static visualizations. I will argue that Study I constitutes a theoretical and methodological contribution to the field of students’ learning from animations. As in the field of students’ learning from simulations, the majority of studies on students’ learning from animations versus static visualizations are experimental intervention studies, based on either a cognitive or a socio-cognitive view of learning. These studies focus primarily on students’ learning outcomes. From a socio-cultural perspective, Study I takes on a mixed methods approach, focusing on both learning outcomes and learning processes. In order to investigate students’ learning processes, the study examines the interactions taking place among students as they attempt to make sense of animations and static visualizations of protein synthesis.

3.2.2 Instructional Design

The instructional design plays a central role in computer-based settings, since it impacts both social and cognitive processes evoked by the students. Several studies have focused on how to optimize student learning by focusing on various instructional design models (Donnelly et al., 2014; Gunckel, 2013; Kalkanis, Hadzidaki, & Stavrou, 2003; Lund & Rasmussen, 2008). The empirical settings studied in the current thesis involve instructional models referred to as “contrasting cases” (Schwartz & Bransford, 1998) and “the jigsaw model” (Aronson, Bridgeman, & Geffner, 1978; Brown et al., 1993). It is, therefore, relevant to review studies that focus on settings in which these two instructional methods are applied. In the following, I will first review studies on the contrasting cases model before reviewing studies on the jigsaw model.

Quite a few studies on students’ learning from contrasting cases have been conducted in different domains (e.g., Loewenstein, Thompson, & Gentner, 2003; Rittle-Johnson & Star, 2009; Schwartz, Chase, Oppezzo, & Chin, 2011). In this learning method, students compare
and contrast instructional materials that display two versions of the same product that are (slightly) different. Examples of products include solutions to math problems, texts, diagrams, etc. The idea behind contrasting cases as a method for learning is that the differences between the two cases will help students focus—and, thus, better reflect on the specific features of the product. Studies have focused on the instructional design of contrasting cases versus designs in which students work on single cases (Baker, Corbett, & Koedinger, 2004; Loewenstein et al., 2003; Rittle-Johnson & Star, 2007) or versus other instructional designs, such as tell-and-practice instruction (Schwartz & Martin, 2004). Studies have also compared variations within the instructional design of contrasting cases (Jee et al., 2013; Rittle-Johnson & Star, 2009; Schwartz & Bransford, 1998; Schwartz et al., 2011). There seems to be a consensus among researchers that the contrasting cases approach is an effective instructional design for student learning, since all of the reviewed studies report positive findings in favor of contrasting cases. Specifically, contrasting cases are proven to be effective in preparing students to learn from teacher lectures and in transferring knowledge from one learning situation to another (Schwartz & Bransford, 1998; Schwartz et al., 2011; Schwartz & Martin, 2004). Moreover, working with contrasting cases may help students pay attention to specific features or information in the instructional material, which they may otherwise overlook (see Bransford, Franks, Vye, & Sherwood, 1989; Schwartz et al., 2011). Currently, there seems to be a lack of studies on students’ learning from contrasting cases related to digital tools. However, related to the instructional design of contrasting cases is the principle of “distinguishing between ideas,” which is one of the principles of the Knowledge Integration Framework developed by the WISE (Web-based Inquiry Science Environment) research group as a guideline to promote coherent understanding in science (Linn & Eylon, 2011). This principle becomes evident in the WISE computer-based learning environment, which contains specific digital tools to support students in comparing and contrasting their own created ideas with the aim of refining their ideas through the process of developing scientific understanding of specific phenomena (McElhaney, Matuk, Miller, & Linn, 2012).

The second focal instructional model, the jigsaw model, refers to a specific method of structuring collaboration to enable students to put together different parts of knowledge to extend their frontiers of knowledge within a group (Aronson et al., 1978; Brown et al., 1993). In this method for organizing learning, each member of the basic group is assigned an expert role, and, for a certain period of time, students with the same expert role work in inquiry-based expert groups. The students then return to their basic groups to teach the topics in
which they have become experts. Research shows diverse findings on students’ learning outcomes when working within a jigsaw model. Several studies in science and mathematics have shown positive learning outcomes for the jigsaw method compared to traditional teacher-centered methods (Doymus, Karacop, & Simsek, 2010; Karacop & Doymus, 2013; Tarhan & Sesen, 2012) or individual learning methods (Doymus, 2008; Lazarowitz, Hertz-Lazarowitz, & Baird, 1994). However, other studies in these domains show lower or equal academic performance for students within the jigsaw condition than students in the traditional condition (Hänze & Berger, 2007; Souvignier & Kronenberger, 2007) or students in the collaborative non-jigsaw condition (Zacharia, Xenofontos, & Manoli, 2011). Brown et al. (1993) describes four classroom climate criteria required for the jigsaw model to be a success (p. 199). These are: 1) individual students take responsibility for searching and sharing knowledge; 2) all individuals respect each other; 3) the instructional setting represents a community of discourse; and 4) the instructional setting is structured and simple to understand. Taking into account the divergent findings from research on the jigsaw model, this indicates that the jigsaw model may be an effective instructional model for teaching and learning only under certain conditions. The current thesis adds to the body of research focusing on the instructional design in two ways. First, it presents a model for how comparing and contrasting simulation ELOs create learning opportunities (Study II), and second, it focuses on how the instructional design of the jigsaw model is intertwined with other support aspects (i.e., peer collaboration, instructional design, and teacher interventions) (Study III).

### 3.2.3 Peer collaboration

The role of peer collaboration in student learning is a huge field, and numerous studies have been performed to investigate the different educational aspects of peer collaboration. Peer collaboration also constitutes a central aspect of the findings of all three studies (Study I, II, and III) of the current thesis. Thus, it is relevant to review studies targeting the role of peer collaboration in student learning. In existing studies, a diverse set of concepts is used to refer to students’ collaborative activities: elaborations (van Boxtel, van der Linden, & Kanselaar, 2000), argumentations (Baker, 2003; Osborne, Erduran, & Simon, 2004), elicitation (King, 1994; Linn & Eylon, 2011), explanations (Webb et al., 2009), and reasoning (Mercer, Dawes, Wegerif, & Sams, 2004). A common feature of the mentioned activities is that students’ thinking is made visible as the students articulate their ideas for each other (Linn & Eylon, 2011; Osborne et al., 2004; Wegerif & Mercer, 1997). The assumption is that collaborative
processes enable a shared understanding. The overall finding of these studies is that peer collaboration is effective for supporting social and cognitive processes in student learning (Howe, Duchak-Tanner, & Tolmie, 2000; Linn & Eylon, 2011; Mercer, 2004; Scardamalia & Bereiter, 2006; Stahl, 2006). However, studies also demonstrate that students’ collaborative processes are not straightforward (Barron, 2003; Furberg & Arnseth, 2009). When students are left on their own in collaboration process, they may not elaborate on or elicit each other’s ideas or explain and justify their reasoning. Hence, the quality of students’ interactions may be insufficient to support learning in an effective manner.

Two strains of research have targeted this challenge. One strain has focused on how to cultivate students’ talk and collaboration processes over time, including how to address disagreements and opposing views regarding scientific explanations or the problem to be solved (Howe et al., 2000; Mercer, 2004). For instance, Mercer, Wegerif, and Dawes (1999) demonstrated that the cultivation of collaborative processes improved students’ learning outcomes. In this study, the teachers raised students’ awareness of their own talk and introduced the students to specific “ground rules” with the aim of stimulating exploratory talk. Exploratory talk can be characterized by constructive criticism, through which students engage critically with one another’s ideas. Mercer et al. (1999) found that a teaching program on exploratory talk was beneficial for students’ abilities to reason and solve problems. The second strain of research targeting the challenge of students’ interaction quality has focused on how computers may shape the ways in which students collaborate with one another, either through computer-based collaboration scripts (Kobbe et al., 2007; Noroozi, Weinberger, Biemans, Mulder, & Chizari, 2013; Weinberger & Fischer, 2006) or through specific digital tools that evoke communication and collaboration (Donnelly et al., 2014; Fischer, Bruhn, Gräsel, & Mandl, 2002). For example, in a laboratory experiment involving 60 university students, Noroozi et al. (2013) demonstrated that scripts prompting students to paraphrase, criticize, prompt counter arguments, ask meaningful questions, and propose argument syntheses facilitated the students’ argumentative knowledge construction and also supported the students’ acquisition of domain-specific and domain-general knowledge of argumentation.

In sum, several studies have pointed out the value of peer collaboration in supporting the development of social and cognitive processes in student learning. The current thesis adds to this body of research by focusing on peer collaboration as an aspect intertwined with other support aspects (e.g., digital tools, instructional design, and teacher intervention). The socio-cultural perspective emphasizes that social processes create conditions for learning; however,
more research is needed to investigate these conditions to further understand the role of peer collaboration in students’ learning processes—and, specifically, to understand participants’ conceptual sense-making in different knowledge domains. The current thesis explores peer collaboration as it is seen in relation to the digital tools of animation (Study I) and computer simulations (Study II and III); to the instructional designs of contrasting cases (Study II) and the jigsaw model (Study III); and to teacher interventions (Study III).

3.2.4 Teacher interventions

An extensive body of research has focused on peer collaboration; however, few studies have focused on the role and significance of the teacher in collaborative settings (Dekker & Elshout-Mohr, 2004; Webb et al., 2009), and even fewer have addressed teachers’ role in supporting students’ collaborative work in computer-based settings (Greiffenhagen, 2012; Urhahne, Schanze, Bell, Mansfield, & Holmes, 2010; van Leeuwen, Janssen, Erkens, & Brekelmans, 2013). A number of studies have reported that specific types of teacher interventions in small group settings enhance the quality of group discussions (Dekker & Elshout-Mohr, 2004; Gillies, 2004; Webb et al., 2009). Webb et al. (2009) investigated the quality of students’ discourse subsequent to teacher interventions, and they found that teacher interventions that probed students’ explanations in order to detect their thinking and problem-solving strategies were especially effective in promoting productive discourse among the students. Dekker and Elshout-Mohr (2004) found that teacher interventions related to students’ interactions, such as interventions prompting students to show, explain, and justify their ideas, were more effective in terms of students’ learning outcomes than content-related interventions, such as hinting about mathematical content.

These results are in line with the results of research on teachers’ interventions on students’ collaborative work in computer-based settings. A study conducted by Greiffenhagen (2012) argues that it is important to understand the role of teacher interventions in computer-based collaborative settings in order to support teachers in engaging in productive interventions in these settings. Another study performed within a computer-based setting investigated what types of interventions are most effective with regard to students’ conceptual understanding (Hakkarainen, Lipponen, & Järvelä, 2002). This study reports that indirect interventions, such as prompting questions or encouraging students to retrieve science-based information, are superior to direct interventions, such as descriptive explanations or prompting fact-based student responses. In a study on the role of the teacher in a computer-
based setting, Urhane et al. (2010) investigated teachers’ employment of four different computer-based learning environments (WISE, Co-Lab, MAC, and ReCoIL). Based on data from questionnaires Urhane et al. (2010) found that teachers play a very important role in facilitating students’ learning. They conclude that none of the four computer-based learning environments outperformed the teacher. The study reported on teachers motivating student learning, supporting students’ use of tools, answering questions, and clarifying difficulties. Although little research has been conducted on teacher interventions in computer-based settings when students collaborate on making sense of content knowledge, the role of teachers in these settings is widely recognized (Dolonen & Ludvigsen, 2012; Greiffenhagen, 2012; Urhahne et al., 2010).

Few process-oriented studies have been conducted exploring the role of the teacher in computer-based settings. Moreover, few studies have focused on the role of the teacher while accounting for coexisting support aspects. Study III (Strømme & Furberg, 2015) targets this research gap by adopting a socio-cultural perspective that involves a focus on the process through which a teacher supports students’ conceptual sense-making as they work collaboratively in a computer-based setting. The study demonstrates the complex role of the teacher as it unfolds in the intersection of the support aspects of digital tools, peer collaboration, and instructional design.

Although there exist quite a few studies supporting students’ learning during collaborations in computer-based settings, we need deeper knowledge of the learning activity through which student-teacher and student-student interactions take place in such settings. By taking a socio-cultural perspective on learning and by focusing on students’ learning processes as they unfold through an activity, the current thesis provides in-depth information about how students make sense of digital tools, such as animations and simulations, as well as how teacher interventions, peer collaboration, and instructional design support students’ development of conceptual understanding. In so doing, the current thesis illustrates the complexity inherent in facilitating students’ development of conceptual understanding in computer-based settings.
In this chapter, I will present the empirical contexts of the three studies conducted as part of the current thesis. Two of these studies are based on data from the Viten.no project. In the following, I will present information about the two projects (SCY and Viten.no); the two computer-based learning environments (SCY-Lab and Viten.no) used by the students; the digital representations addressed in the three studies (simulation in SCY-Lab and animation in Viten.no); the schools and the students; and the student projects in all three studies. The SCY project, and one study

4.1 The Science Learning by You (SCY) project

The SCY project (de Jong et al., 2010; de Jong et al., 2012) was a European design-based research project. The main aim of the SCY project was to develop a computer-based learning environment for science topics based on specific design principles and to study students’ learning when interacting with this learning environment, which is called SCY-Lab. The target group was students between 12 and 18 years old. The project, which was active from 2008 to 2012, was financed by the European Union and involved the participation of twelve institutions from seven countries. One of the key partners was InterMedia at the University of Oslo (UiO). Three periods of data collection were conducted by the Oslo research group during the spring of 2010, the spring of 2011, and the fall of 2011. I joined the project in 2010 and, thus, participated in the data collection for all three iterations. I also participated in all internal SCY research meetings at the InterMedia group; however, I was not involved in research meetings taking place among all the participating partners—and, thus, was also not involved in the design of SCY-Lab. Nevertheless, together with the teachers and other researchers in the SCY research team in the two data collections, I was involved in developing the instructional design. Prior to the student project, the research team presented SCY-Lab and the instructional design embedded in SCY-Lab to the teachers. Then, together with the teachers, we modified the instructional design to fit the Norwegian science curriculum. We also planned a detailed schedule for the student project together with the teachers. This approach was taken to help the teachers develop ownership of SCY-Lab and its’

3 The SCY project was funded by the European Community under the Information and Communication Technologies (ICT) theme of the Seventh Framework Programme for R&D (Grant agreement 212814) ([http://www.scy-net.eu/](http://www.scy-net.eu/)).
embedded instructional design. My PhD position was not funded by the SCY project; however, for five months, I took leave from my PhD position to work for the SCY project on data collection and reporting. Two of the studies in the current thesis (Study II and III) are based on data from the SCY project.

4.1.1 The SCY learning environment (SCY-Lab)

The SCY learning environment (SCY-Lab) is a curriculum-based learning environment designed for students aged 12 to 18 to work on specific topics in science, such as heat loss and the greenhouse effect or forensic DNA. The pedagogical idea behind SCY-Lab is that students learn from working collaboratively on solving “missions” and from creating digital student products, termed Emerging Learning Objects (ELOs). The missions are guided by questions like, “How can we design a CO₂-friendly house?” or “How can we produce healthier milk?” To solve these missions, students must combine knowledge from different disciplines, such as mathematics, physics, biology, and engineering. Students can choose among different activities and tools to solve the missions, and, during the solution process, the students create ELOs, such as results from simulations, mind maps, or notes. Students undergo iterative processes when refining their ELOs, and the pedagogical idea behind ELOs is that students develop conceptual understanding through this refining process. All ELOs are accessible to all students in class through a search tool embedded in SCY-Lab, which allows the students to learn by examining each other’s products.
A central tool in this thesis (*Study II* and *III*) is the simulation tool (see Figure 1). By altering different parameters, such as wall thickness and the material used in walls, students can calculate the total heat loss from a house. For a detailed description of the simulation tool, see *Study II* and *Study III*. Each of these two studies has a different analytical focus with regard to the simulation tool. In *Study II*, the analytical attention is on students’ manipulation of the simulation tool, specifically when examining peer-created simulation data through own simulation data. In *Study III*, the focus is on the simulation tool as one of four integrated support aspects taking place in students’ learning processes. I chose to focus on students’ interactions with the simulation tool, since this tool teaches central scientific concepts (e.g., heat transfer) and is a central resource in supporting students’ development of conceptual understanding within SCY-Lab.

### 4.1.2 Empirical context (*Study III*)

*Study II* and *Study III* are based on data from two different data collections in the SCY-project: respectively, the first and second data collection. I have chosen to account in detail for the empirical context of the data collection constituting the empirical grounding for *Study III*. In *Study II*, the analytical attention is on students’ manipulation of the simulation tool, specifically when examining peer-created simulation data through own simulation data. In *Study III*, the focus is on the simulation tool as one of four integrated support aspects taking place in students’ learning processes. I chose to focus on students’ interactions with the simulation tool, since this tool teaches central scientific concepts (e.g., heat transfer) and is a central resource in supporting students’ development of conceptual understanding within SCY-Lab.
Both data collections are described in certain detail in the articles; in addition, the description of the empirical context for Study II resembles, to some extent, the empirical context for Study III. However, the data collection for Study III was carried out over the course of two weeks in March 2011. The school selected for this data collection was a multicultural high school in the central area of Oslo. A total of 40 students from two grade 11 classes participated in the project. Both classes were selected by the principal, based on the criterion of having experienced teachers. We decided to work closely with the teachers prior to the student project so that the teachers could establish ownership of the student project. We also sought to secure a mutual understanding between researchers and teachers regarding how the student project should be carried out. During the course of six workshops, we planned the student project in detail and demonstrated all of the features in SCY-Lab. In these workshops, we also modified the curriculum in the student project to fit the national science curriculum in order to make the project more relevant for students.

The project was carried out during 20 school hours on nine different days (two to four hours a day) over the course of two weeks. The students’ mission was to design a “CO₂-friendly building.” Specifically, the students were assigned to create a sketch of their building using the 3D modeling computer program Google Sketch Up. A math tool embedded in SCY-Lab allowed the students to construct the ground floor of the house based on specific premises. The sketch of the ground floor was then imported into Google Sketch Up to facilitate the further design of the house. As described above, SCY-Lab also contained a simulation tool to calculate the total heat loss of the house. All of the parameters in SCY-Lab (e.g., the total areas of walls, windows, floor, and roof) had to match the actual design of the house created in Google Sketch Up. Since the students’ task was to design a “CO₂-friendly building,” the design of the house sketch and the choice of parameters in the simulation could be seen as “bootstrapping” operations, in which the premises and results of the house sketch and the simulation tool influenced one another. All design choices were accounted for in the final product, which was a Power Point presentation. The students were also told to include the house sketch, the simulation results, and information from each of their expert areas in their final Power Point presentations.

The student projects were based on the adapted jigsaw model (Aronson et al., 1978; Strømme & Furberg, 2015), which suggests that students should alternate between working in basic groups and working in expert groups. Each student in the basic groups was assigned one of four designated “expert fields:” heat pumps, solar panels and collectors, heat loss and
insulation, or new renewable energy. The students were then organized into expert groups based on their fields, and each expert group was asked to produce a one-page written description of the expert topic. When the students returned to their basic groups, each student presented his or her topic of expertise to his or her peers. In this way, each basic group was dependent on its members’ expertise for success in the project. Students worked for four hours in their expert groups; thus, the majority of the group work took place in the basic groups. The students worked in groups of four in the basic groups. Within each group, students worked in dyads, sharing one computer per dyad.

Table 2: Overview of the student project in Study III

<table>
<thead>
<tr>
<th>Day</th>
<th># of Lessons</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>2 lessons</td>
<td>Plenary session:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Introduction to the mission</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Introduction to SCY-Lab, including the simulation tool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Lecture given by a civil engineer on the design of CO₂-friendly houses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Mobilization of students’ prior knowledge, work on mind-map ELOs</td>
</tr>
<tr>
<td>Day 2</td>
<td>4 lessons</td>
<td>Group work in basic groups</td>
</tr>
<tr>
<td></td>
<td>(180 min)</td>
<td>Group work in expert groups according to expert topics:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. Heat pumps</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Solar panels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. New renewable energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Heat loss and insulation</td>
</tr>
<tr>
<td>Day 3</td>
<td>2 lessons</td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Sharing expert knowledge</td>
</tr>
<tr>
<td>Day 4</td>
<td>2 lessons</td>
<td>Plenary session:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Introduction to math tool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Use of math tool</td>
</tr>
<tr>
<td>Day 5</td>
<td>2 lessons</td>
<td>Plenary session:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Introduction to Google Sketch Up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Continue work on math tool</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work on house sketch ELO in Google Sketch Up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work on simulation ELO</td>
</tr>
<tr>
<td>Day 6</td>
<td>4 lessons</td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td>(180 min)</td>
<td>- Collaboration with students in the Netherlands using chat</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Continue work on house sketch ELO in Google Sketch Up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work on simulation ELO</td>
</tr>
<tr>
<td>Day 7</td>
<td>3 lessons</td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td>(135 min)</td>
<td>- Continue work on house sketch ELO in Google Sketch Up</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work on simulation ELO</td>
</tr>
<tr>
<td>Day 8</td>
<td>2 lessons</td>
<td>Group work in basic groups:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Work on Power Point presentation</td>
</tr>
<tr>
<td>Day 9</td>
<td>2 lessons</td>
<td>Plenary session:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>- Group presentation</td>
</tr>
</tbody>
</table>
The interaction trajectory of the student project was as follows (see Table 2): The project started with the students watching a short video in which they were introduced to the topic of the environmental aspects of energy loss from buildings. They were then given the assignment of designing a “CO2-friendly building” by a fictive mayor in the video. Next, the students were introduced to the computer-based learning environment SCY-Lab. In order to make the student project as authentic as possible, the research team hired a civil engineer from a private company to give a lecture on how to design low-energy buildings. After this presentation the students were informed about practicalities, the form of assessment, and the assessment criteria. Subsequent to these plenary sessions, the students went to work in their basic groups. They created mind-maps through SCY-Lab to mobilize prior knowledge on the greenhouse effect and on heat loss and energy sources in buildings. The students also worked in their expert groups and then returned to their basic groups to share their expertise with peers. During the rest of the project, the students worked in parallel in their basic groups on designing the house sketch and running the simulation, while drawing on one another’s expertise from the expert groups. However, in one specific timeslot during this period, the students were invited to chat with students located in the Netherlands who were working on the exact same project. Prior to the chat, the students were assigned topics concerning environmental issues to discuss with the foreign students. The project ended with group presentations in a plenary session, during which the civil engineer was present and commented on students’ presentations. The students were graded individually on the presentation.

4.2 The Viten.no project

The Viten.no project (Jorde et al., 2003; Mork, 2011) is an ongoing design-based research project for designing a computer-based learning environment (Viten.no) for use in science topics in Norwegian schools. The project is housed by the Norwegian Center for Science Education, and the units, which are designed within the computer-based learning environment, are available for teachers and their students free of charge on the Internet4. The target group is students in lower and upper secondary school. The first Viten.no unit was designed in 1999 based on ideas from the WISE learning environment developed at the University of California,

4 www.viten.no
Berkeley (Sørborg, Mork, & Erlien, 2013). However, today (June 2015), Viten.no consists of 22 units in different topics in science. I was introduced to the Viten.no project when I was a master student in 2003/2004. I have not been part of the Viten.no research team; however, my master thesis and Study I in the current thesis are based on data from the Viten.no project.

### 4.2.1 The Viten.no learning environment

Viten.no is a curriculum-based, Norwegian-language science learning environment designed for students aged 10 to 19. Some of the units in Viten.no have been translated to English, Swedish, and Danish. The units’ content is structured according to a clear progression in content difficulty, and students move through page by page interacting with the science content. The pages consist of text, pictures, animations, static visualizations, simulations, videos, interactive tasks, and open-ended tasks. The students’ answers to the open-ended tasks are saved in a digital workbook, to which the teacher also has access and which the teacher may use as a tool for formative assessment. Some of the units focus on socio-scientific questions, such as “Should selling gene-modified food in Norway be allowed?” Other units focus on assignments that only can be solved through the use of science knowledge. In several of the units, the students are assigned a final activity after finishing the unit, such as participating in a debate or writing a newspaper article.

![Figure 2: A snapshot from the animation in Viten.no showing the protein synthesis](image)
A central representation used in the “Gene technology” unit addressed in the current thesis (*Study I*) is an animation and static visualization of protein synthesis (see Figure 2). Protein synthesis is a biological process involving the production of proteins in the human body. For a detailed description of the animation and static visualization of protein synthesis, see *Study I*. The focus of *Study I* is students’ sense-making of animation versus static visualizations of protein synthesis. I chose to focus on protein synthesis firstly because it is dynamic in nature—and, in contrast to static visualizations, animations may capture changes that take place in a process over time (Marbach-Ad et al., 2008; Yarden & Yarden, 2010). Secondly, protein synthesis is very complex for students to understand, since the process takes place on the micro level (invisible to the naked eye) and since it is closely connected to a network of other science concepts with which students do not have everyday experience (Gericke & Wahlberg, 2013; Starbek et al., 2010). The nature of protein synthesis as a process with a high level of complexity constituted the main argument for focusing on this concept when choosing among different visualized concepts in the Gene Technology unit.

**4.2.2 Empirical context (*Study I*)**

The data collection for *Study I* was carried out at a lower secondary school in a central area of Oslo. The majority of the students in the school were ethnic Norwegians, and the school was selected according to the criterion of convenience, since I had previously served as a teacher at this school. In sum, 51 students from two general grade 10 science classes participated in the project. All these students had previously been in my own science and mathematics courses. The students’ new science teacher agreed to participate in the study and was instructed to run the science project. I arranged for one meeting prior to the data collection, during which we examined both practical and research-related issues. The student project was carried out during nine school hours (45 min sessions) over the course of two weeks. During the first seven hours, the students worked in front of the computer, using the “Gene Technology” unit in Viten.no. The curriculum of the Gene Technology unit included the composition and function of cells; the composition of DNA; the relationships among genes, proteins, and traits; protein synthesis; DNA replication and cell division; the inheritance of traits; and gene technology in practice, particularly with regard to gene-modified food. The students worked in dyads, sharing one computer per dyad. The teacher circulated among the students and approached the students to assist on request. The last two hours of the student project were allocated to an offline debate about gene-modified food. The intention behind the
debate was for students to use the knowledge acquired from the Viten.no unit when discussing the topic with their peers. (See Table 3 for an overview of the student project in Study I).

Table 3: An overview of the student project in Study I

<table>
<thead>
<tr>
<th>Day</th>
<th># of Lessons</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>2 lessons</td>
<td>Work in dyads in Viten.no</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td></td>
</tr>
<tr>
<td>Day 2</td>
<td>1 lesson</td>
<td>Work in dyads in Viten.no</td>
</tr>
<tr>
<td></td>
<td>(45 min)</td>
<td></td>
</tr>
<tr>
<td>Day 3</td>
<td>1 lesson</td>
<td>Short plenary introduction to cell division</td>
</tr>
<tr>
<td></td>
<td>(45 min)</td>
<td>Work in dyads in Viten.no</td>
</tr>
<tr>
<td>Day 4</td>
<td>1 lesson</td>
<td>Short plenary introduction to inheritance and traits</td>
</tr>
<tr>
<td></td>
<td>(45 min)</td>
<td>Work in dyads in Viten.no</td>
</tr>
<tr>
<td>Day 5</td>
<td>2 lesson</td>
<td>Work in dyads in Viten.no</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>Work in dyads:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Preparation for role play debate.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work on selected newspaper articles about gene-modified food.</td>
</tr>
<tr>
<td>Day 6</td>
<td>2 lessons</td>
<td>Plenary session:</td>
</tr>
<tr>
<td></td>
<td>(90 min)</td>
<td>Students participate in a role play debate about gene-modified food</td>
</tr>
</tbody>
</table>

Every lesson started with the teacher providing practical information about the project in the students’ primary classroom before the students went off to work in pairs in front of the computers, which were located in two separate rooms. The teacher was informed that he could choose to provide a short scientific introduction to a relevant topic at the beginning of each lesson, if he thought that this would benefit the students. He was also informed that he should try to present his instruction as similarly as possible in both classes. The teacher chose to give such an introduction twice: the first topic concerned cell division, and the second topic concerned the inheritance of traits through recessive and dominant genes.
5 Methodology

In this chapter, I will account for the methodology used in the current thesis. Specifically, I will describe the research design, the collection procedures and the data corpus for each of the three studies. I will also describe the empirical analysis performed. My emphasis will be on the video recordings of the social interactions, since these data constitute the core data for my three studies. I conclude the chapter by discussing the validity, reliability, generalizability, and ethical considerations related to my studies.

5.1 Research design

The research in the current thesis can be described as design-based research. There are different ways to understand and conceptualize design-based research, and the studies in the current thesis build on a socio-cultural design-based approach (Krangel & Ludvigsen, 2009). To describe the socio-cultural design-based approach, I will first outline what can be described as the socio-constructivist design-based approach (Collins, Joseph, & Bielaczyc, 2004). In this approach, researchers develop educational designs based on specific design principles derived from theory. They then implement these design in educational settings in order to study how the designs and design principles impact different variables, such as student learning. The main goal of this view of design-based research is to refine educational design. In the socio-cultural design-based approach specific design principles are used to design the learning activities; however, contrary to the more “traditional” design-based approach, the same design principles are not used as part of the analytical framework when analyzing the empirical data. This ensures that the research stays focused on the concerns of the participants and their actual activities—and, hence, may reduce the bias related to focusing only the researchers’ intentions and predefined interests. Although the design principles are independent from the analytical process, the results of the study may have implications for educational design (Krangel & Ludvigsen, 2009).

The three studies (Studies I, II, and III) on which the current thesis is based can be considered case studies. Yin (2014) defines a case study as “a study that investigates a contemporary phenomenon in depth and in its real-world context” (p. 237). In each of the case studies, I am inspired by ethnographic research (Wolcott, 1999), in the sense that I have collected a rich set of different types of data (e.g., interactional video data, field notes,
interview data, pre- and post-tests, and student products). I have also studied students in their natural settings and have provided a rich and detailed description of the activities occurring in this natural setting. Although all three studies focus on students’ and teachers’ interactions in a natural school setting, the design of *Study I* differs slightly from that of the two other studies. *Study I* is a comparative study comparing the educational implications of students working with two different versions of a computer-based learning environment. However, since all three studies involving integrating an instructional design that is partly embedded in a computer-based learning environment into the classroom, each study’s methodological focus has been to investigate students’ and teachers’ interactional achievements when working within the particular instructional design.

Table 4: Overview of types and statuses of data collected

*(BS = Background Status, PS = Primary Status)*

<table>
<thead>
<tr>
<th>Type of data</th>
<th>The SCY project (First data collection, Study III)</th>
<th>The SCY project (Second data collection, Study II)</th>
<th>The Viten project (Study I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video recordings of classroom interactions</td>
<td>PS</td>
<td>PS</td>
<td>PS</td>
</tr>
<tr>
<td>Pre- and post-test data</td>
<td>BS</td>
<td>BS</td>
<td>PS</td>
</tr>
<tr>
<td>Student interviews (group)</td>
<td>BS</td>
<td>BS</td>
<td>Not collected</td>
</tr>
<tr>
<td>Student interviews (individual)</td>
<td>Not collected</td>
<td>Not collected</td>
<td>PS</td>
</tr>
<tr>
<td>Teacher interviews (group)</td>
<td>Not collected</td>
<td>BS</td>
<td>Not collected</td>
</tr>
<tr>
<td>Field notes</td>
<td>BS</td>
<td>BS</td>
<td>BS</td>
</tr>
<tr>
<td>Digital products</td>
<td>BS</td>
<td>BS</td>
<td>BS</td>
</tr>
</tbody>
</table>

In all three data collections, my colleagues and I have collected more types of data than we have made use of in the three studies (*Studies I, II, and III*). We followed the ethnographic approach of collecting a rich set of data to give me the flexibility of later deciding which data to use. In the context of group research, this approach also caters to different researchers’ different interests in different types of data. In all three studies, therefore, we have selected and analyzed the types of data that we believe have answered the
stated research questions. Studies II and III are qualitative studies that build primarily on video-recorded interactional data from students’ work in class. Study I is a mixed method study that also builds on video-recorded interactional data, but that also incorporates data from student interviews and pre- and post-tests. In all three studies, field notes and student products were used as background information. For an overview of types of data collected and their statuses, see Table 4.

5.1.1 Video-recording classroom interactions

In all three studies, I have video-recorded classroom interaction. Video recording is a way of collecting a rich set of data from a classroom (Derry et al., 2010; Jordan & Henderson, 1995), and, in all three studies, we video recorded dyads and groups of students working in front of the computer during the entirety of the student project. In all the three studies, the students were instructed to share one computer between two students. The students were organized in this way to support peer collaboration, but also to increase the amount of interactional data for methodological purposes. We decided to video-record three student groups for each of the two data collections in the SCY project (Studies II and III), as well as four dyads from each of the two classes in the data collection in the Viten.no project (Study I). In our attempt to minimize the number of cameras due to practical issues (e.g., collecting an overload of data), we decided that focusing on three and four groups (for Studies II and II and Study I, respectively) would be sufficient to display the diversity of the groups. In all three data collections, we also video-recorded the teachers’ plenary instructions in class.

In both data collections in the SCY project, our research group included four researchers who collected the data. Three of us were responsible for filming one group each. Despite being aware of the potential observer effect, we decided to sit next to each group, listen to the group conversations, and take field notes of said conversations. In this way, we were able, at an early stage, to get an overview of the data material. My role as a researcher in collecting data in the SCY-studies can be described as that of a non-participant observer. In the Viten project, two researchers were involved in collecting the data. We shared responsibility for operating the four cameras in each of the two classes. In this data collection, we did not sit next to the student dyads to listen to their conversations; thus, our role as researchers can mainly be described as that of a non-participant observer (although, in some occasions, we acted as participant observers). We never approached the students during their work on our own imitative; however, when students summoned the teacher and the teacher
was busy supporting other students, we decided to answer practical and closed questions. All conceptual or open-ended questions were directed to the students’ teacher.

In all three data collections, the video cameras were located behind the students, pointing in the direction of the computer screen. This was done in order to capture the content on the computer screen that the students were making sense of, as well as to capture the students’ gestures when interacting with the representations on the computer screen. External microphones were used in all three studies to optimize sound. In the SCY project, the students worked in groups of four; however, although we captured the sound of all four students in the group, we only captured the image of one of the two dyads at a time. When the two dyads within the group decided to work on different tasks, we prioritized to video record the dyad working on the simulation tool.

5.1.2 The interview conversations

The data in Study I also consist of individual interview conversations (Saxe et al., 2015). I decided to interview the same students that were video recorded during class to further explore these students’ conceptual understanding of different topics (i.e., the composition of cells, the composition of DNA, cell division, and protein synthesis). These topics were of specific interest, since they were represented in different ways (i.e., animations and static visualizations) in the two versions of the Viten.no unit. As the interviews proceeded, I noticed that the students’ answers repeated across the two classes. Therefore, I decided to leave out one dyad within each of the two classes, resulting in a total of 12 interviews. The interviews were conducted in front of the computer in order explore the students’ sense-making when interacting with the representations. First, the students were introduced to the familiar type of representation (animation or static visualization), with which they had been working in class. The aim of this approach was to explore how students made sense of the representation while supported by a more knowledgeable person. Next, the students were introduced to the unfamiliar representation format (dynamic vs. static format)—that is, the format that they had not seen prior to the interview conversation. The aim of this was, first and foremost, to explore how students in the static condition made sense of the animation and to determine whether this new type of representation increased the students’ understanding of the science topic. An additional aim was to explore the students’ reflections of their own imaginary learning from animations versus static visualization. Just as we did when video recording the classroom interaction, I placed a camera behind the student in order to capture the content on
the computer screen, as well as the student’s and my own gestures when pointing to the screen.

The individual interview conversations were conducted as part of the socio-cultural perspective outlined in the theoretical section. The conversations can be seen as situated interactions between single students and the researcher, and representations depicted in the Viten.no may also, in this situation, be seen as tools mediating the conversations. Further, the conversations investigated the students’ conceptual understanding at specific points in time, while simultaneously investigating the process of students’ development of conceptual understanding while interacting with the digital tool and a more knowledgeable person. However, within a socio-cultural approach, the data collected at the individual level are not used in isolation; instead, they are amalgamated with data displaying the social context of which the individual is part. For Study I, this meant that the analysis of interview data of individual students constituted a supplement to the analysis of the interactional data collected in the naturalistic classroom setting, of which each individual student was a part.

5.1.3 Pre- and post-tests

The pre- and post-tests used in Study I were designed as part of my master thesis. In order to strengthen the credibility of the study (see section 5.3, Research credibility), I decided to reanalyze all of the tests. I made use of the same coding scheme that I used for my master thesis. As a master student, I designed the tests together with a PhD student, under the close supervision of Prof. Doris Jorde. Since this PhD student’s study had another focus, we included questions that would also target her research interests. These questions, along with the questions that did not meet the coding criteria of being coded according to a 4-point coding scale, were removed from the test. Thus, a total of 16 items were removed from the test, leaving 19 remaining items. For a description of the data collected in the three studies, see Tables A, B, and C in the appendix.

The pre- and post-test data target individual students’ understanding of gene technology at two specific points in time: prior to and after the student project. However, as with the data from the individual interview conversations, the pre- and post-test data were not used in isolation of the interactional data. In Study I, the pre- and post-test data were used to measure possible differences between the two classes’ learning outcomes, and these analyses complemented the analysis of students’ interactions in naturalistic classroom settings. The
interactional data were primarily used to explain the differences between the two classes with regard to students’ learning outcomes on the pre- and post-tests.

5.2 Analytical procedures

5.2.1 Interaction analysis (Study I, II, and III)

The qualitative data in the current thesis were analyzed using a version of the method of interaction analysis of Jordan and Henderson (1995). Interaction analysis can be defined as an “interdisciplinary method for empirical investigation of the interaction of human beings with each other and with objects of their environment. It investigates human activities, such as talk, nonverbal interaction, and the use of artefacts and technologies, identifying routine practices and problems and the resources for their solution” (Jordan & Henderson, 1995, p. 39). Hence, a fundamental assumption in interaction analysis is that cognition is socially constructed through collaborative sense-making and interaction with artefacts. In the version of interaction analysis employed in the current thesis, the analytical focus is on how the content of the conversation is produced through language; however, the analytical focus is not the language itself (Furberg & Arnseth, 2009; Krange & Ludvigsen, 2008).

Before describing how we analyzed the data according to the described method of interactional analysis, I will describe how we defined the evidence—that is, the procedure taken on for selecting the excerpts constituting the evidence in the three studies (Studies I, II, and III). The method of interaction analysis cannot be seen as a separate process from selecting excerpts (Jordan & Henderson, 1995). In qualitative research in general, research questions and assertions do not have to be defined prior to the data collection. According to Erickson (2012), “in qualitative research, analysis is a boot-strapping operation in which, reflexively, assertions and questions are generated on the basis of evidence, and evidence is defined in relation to assertions and questions” (p. 1458). The procedures used to select the evidence were slightly different for the three studies; however, in general, the selecting procedure can be described as follows: Prior to the three data collections, we began with broad, thematic questions or themes of focus. After collecting the data, we studied the video recordings and searched through the rest of the data to gain an overview of what the data revealed about our selected themes. In this initial phase, we also roughly transcribed the video recordings. The process of transcribing video recordings made us more familiar with the data.
Based on our new insight into the data, we refined our research questions. Further, we scrutinized the transcribed video recordings to search for evidence related to our research questions. During this search for evidence, we tried to identify “smaller units of coherent interaction” (see Jordan & Henderson, 1995: 57)—here called segments. In order to identify the beginning and end of each segment, we searched for naturally segmented stretches of interaction (see ibid). Further, through this search for segments, a narrative structure (or story) emerged from the data for each study (see Derry et al., 2010, p. 11), and we selected segments that displayed this narrative structure. Once we had defined the narrative structure, our selection process had reached the level at which we had to compare segments located next to one another. As we selected among excerpts, all of which displayed the same piece of narrative structure, we selected excerpts that would best display the analytical focus addressed by our research questions. After identifying final segments, we re-transcribed the segments at a detailed level.

In two of our studies (Studies I and III), we use the notion of an “interaction trajectory” (Ludvigsen, Rasmussen, Krange, Moen, & Middleton, 2011) to refer to the narrative structure displaying the analysis of a set of interactions over time. As described by Barnes (1992), “Most learning does not happen suddenly; rather, the construction of knowledge and understanding evolves over time: ‘we do not one moment fail to understand something and then the next moment grasp it entirely’” (p. 123). By analyzing selected chronological excerpts of students’ interactions over time, we have been able to show the changes that take place in students’ conceptual sense-making, as well as to determine how different resources and support aspects influence students’ sense-making processes. In Study II, the narrative structure does not display interactions over time; instead, it displays the interactions of three different groups working on the same task. Hence, the narrative structure can be characterized by the interactional differences among the three compared groups.

In Studies II and III, we use the set of analytical concepts related to the perspectival framing addressed in the theoretical section. 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 display how individual students contribute to other students’ development of conceptual understanding. Put differently, the analytical concepts facilitate an integrated view of how social and cognitive (individual)
processes are played out, while, at the same time, differentiating between the sources of knowledge construction and how social aspects contribute to this production.

Students’ collaborative sense-making of the representations cannot be understood in isolation from the representations themselves. Since the representations are detailed and complex in nature, and since the dynamic aspects of the animation change the representations over time, the students constantly refer to different parts of the representation throughout the conversation. Thus, in Study I, we have chosen to present images of all the different computer screens related to the students’ sense-making processes next to the excerpts, and we have connected the two types of representations (text and image) with arrows. Every time a student points to specific parts of the representation on the screen, we have drawn an arrow from the end of that utterance in the excerpt to the corresponding portion of the representation. These arrows and images are designed to make the excerpts more accessible to the reader. This issue will also be accounted for in section 7, Discussion.

5.3 Research credibility

5.3.1 Reliability

In qualitative research, reliability pertains to “the consistency and trustworthiness of research findings; it is often treated in relation to the issue of whether a finding is reproducible at other times and by other researchers” (Brinkmann & Kvale, 2015). In order to make findings reproducible, it is important to minimize the degree to which “the findings is independent of accidental circumstances of the research” (Kirk & Miller, 1986, p. 20). The goal of reliability is to “minimize the errors and biases in a study” (Yin, 2014, p. 49). Hence, reliability is related to methodological transparency and the production of data—and, thus, to the quality of data with respect to the phenomenon under investigation.

Video recordings as data, have a strong position with regard to reliability, since data are captured on reviewable records—and, thus, are not dependent on humans as instruments for data production (e.g., as in the case of field notes). However, in video studies, human errors may occur in transcriptions; thus, reliability is closely connected to the transcribing process (Silverman, 2001). My studies have used a modified version of the standardized transcription notation developed by Jefferson (2004). However, this transcript notation is developed for audio—not video. As far as I know, no standardized transcript notations have
been developed that explicitly take into account the visual aspect of interaction analysis. Of the three studies on which the current thesis is based, the video recordings collected in Study I were the most complex to transcribe. In the video data in Study I, the students made a substantial amount of references to the representations on the computer screen. Many of the utterances were incomplete, since their utterances were often interrupted by new movements in the animation, which stimulated new responses. Therefore, I had to play the video recordings over and over to ensure that the visual aspects of the video recordings were sufficient and accurately accounted for. The research community played a vital role in the process of deciding how to present the transcripts. When presenting early versions of my transcripts to fellow researchers who had not seen the original video recordings, it became evident that it was very difficult for them to grasp whether or how an utterance was a response to a visual aspect on the computer screen. Thus, as described in section 5.2.1, Interaction analysis, I decided to include arrows and snapshots from the animations to make the video recording transcripts more accessible to the reader. Moreover, for all three studies, after selecting the excerpts to be included in the articles, I re-transcribed the excerpts on a detailed level in order to increase the study’s reliability.

Transparency is important for convincing a reader of the quality of data and the quality of the process leading to the production of the data (Peräkylä, 2011; Silverman, 2001). It also facilitates the possible reproduction of the study. In section 4, Empirical context, and section 5, Methodology, I have made a considerable effort to make the study as transparent as possible with regard to the different stages of the research process—and, thereby, to increase the reliability of the study. As a final comment, I will address the issue of reliability in quantitative research, since one of my studies (Study I) is a mixed method study based on data from pre- and post-tests. In quantitative research, reliability is tested by means of various statistical tests. I used the median Cohen’s kappa to test the inter-rater reliability. The calculated value was $d = 0.76$ [0.2-1.0], which indicates a high inter-rater reliability.

### 5.3.2 Validity

In the social sciences, validity pertains to “the degree that a method investigates what it is intended to investigate” (Brinkmann & Kvale, 2015, p. 282) and to “whether or not the inferences that the researcher makes are supported by the data, and sensible in relation to earlier research” (Peräkylä, 2011, p. 365). Hence, validity is related to the credibility of our interpretations of the data.
I have made a substantial effort to increase the validity of my study. The risk of individual bias can be reduced by involving the scientific community in the analytical process. Thus, in order to strengthen the credibility of my research, I have discussed my data (i.e., the video recordings and transcripts) and my analyses of the excerpts in different research groups. In addition, the method of interaction analysis is a type of method that is quite transparent to the reader of the study, since the excerpts are included in the article. The expression validation through next turn refers to the inherent methodological transparency of analyzing talk in interaction (Peräkylä, 2011; Sacks, Schegloff, & Jefferson, 1974). That is, in the unfolding of an interaction, one utterance is connected to the next utterance through the interlocutors’ interpretation of the previous utterance. In other words, each utterance tells us something about the speaker’s understanding of the previous utterance. Since the analysis in the current thesis builds on this principle, the reader can judge for herself the extent to which the inferences I make are supported by data.

Validity can also be seen as quality of craftsmanship (Brinkmann & Kvale, 2015). In ethnographic case studies, it is important to present enough information about empirical context and methodological considerations to convince the reader of the credibility of the study. This is a matter of transparency. In the current thesis, I have provided a detailed description of the particular context and the methodological choices made in all three studies. Moreover, for each of the studies, I have carefully described how we selected the students and the extracts to be used.

A combination of data (i.e., triangulation) strengthens the validity of a study, since different types of data are included to support the study’s interpretations and claims (Creswell, 2014). Study I is based on three types of data: video recordings of interactional data, interview data, and pre- and post-test data. We chose to include all three types of data in order to make the research design more robust with regard to validity. Each type of data strengthened the overall claim of our article (i.e., that animations are superior to statistic visualizations in students’ learning of protein synthesis). However, different types of data also illustrated different aspects of the phenomenon being investigated (e.g., the interactional data provided in-depth information explaining the pre- and post-test results). A potential threat to validity in studies in which people know that they are being observed is reactivity. Reactivity can be defined as changes in people’s behavior due to their awareness of being observed (Heath, Hindmarsh, & Luff, 2010). In my study, reactivity is related to the camera effect and the observer effect. These effects should be addressed particularly for Study III, since, in this
study, the researchers sat directly next to the student groups and took notes throughout the entire student project. My interpretation is that the camera and observer effects were evident during the first hour in which the students were observed and filmed. Shortly after the project started, the students spoke freely about their everyday considerations and private lives in-between project-related discussions, seeming to forget about the camera and our presence as observers. In addition, as the former teacher of the students in Study I, I was able to tell that the students did not behave or interact differently than they normally did. Finally, several researchers have shown that students become accustomed to being observed (Heath et al., 2010; Jordan & Henderson, 1995). Based on these reconsiderations, I do not consider reactivity a threat to the validity of my study.

5.3.3 Generalizability

Generalizations in qualitative research refer to analytic generalizations (Brinkmann & Kvale, 2015; Yin, 2014). According to Yin (2014), an analytic generalization “consists of a carefully proposed theoretical statement, theory or theoretical proposition. The generalization can take the form of a lesson learned, working hypothesis, or other principle that is believed to be applicable to other situations” (p. 68). This implies that generalizing from case studies means going beyond the specific case being studied. Further, according to Brinkmann and Kvale (2015), analytic generalizations involve “a reasoned judgment about the extent to which the findings of one study can be used as a guide to what might occur in another situation. It is based on analysis of the similarities and differences of the two situations” (p. 297).

In the three studies (Studies I, II, and III), as well as in the current thesis, the analytic generalizations are explored on a higher level than the specific cases. That is, the generic claims are based on my review of previously conducted studies, on the theoretical perspective outlined, and on the findings from the empirical analysis (Ercikan & Roth, 2009; Yin, 2014). Hence, previously conducted studies in relevant fields of science education and learning sciences are thoroughly addressed. Moreover, the theoretical perspective (i.e., the socio-cultural perspective, on which the current thesis is based), has been described in detail. Further, the empirical findings are discussed in relation to previously conducted studies and socio-cultural theory; thus, the generic claims of the current thesis contribute to the field of science education, the field of learning sciences, and the field of socio-cultural theory. Through the accumulation of more case studies over time, each study contributes to the robustness of the findings of these studies.
The theoretical concepts used in a study may be advanced as part of the analytic generalization. In Studies II and III, we used a set of analytical concepts related to framing (i.e., conceptual framing, positional framing, source, and listener) defined by van der Sande and Greeno (2012). We applied these concepts to a new setting and, in this way, corroborated the value of using these concepts to understand framing in relation to learning opportunities. In addition, based on our theoretical stance (i.e., the socio-cultural view of learning)—and, in particular, on van de Sande and Greeno’s (2012) analytical concepts of framing—we developed a model to explain how compare-and-contrast tasks can create new learning opportunities. This model can be seen as an analytic generalization.

In order for others to judge the analytic generalizations made in this study, it is important to provide detailed and rich contextual and methodological descriptions. The limited format of articles makes it difficult to include extended methodological descriptions; however, the extended abstract of the current thesis contains a detailed and rich description of the design of the study, the data corpus, the empirical context (including a description of the representations in the computer-based learning environments), and the methodological considerations of the study.

### 5.3.4 Ethical considerations

The Norwegian Social Science Data Services (NSD) is the Data Protection Official for Research for the University of Oslo. Since the three studies on which the current thesis is based involved collecting, recording, and storing personal data using a computer, we were required to fill out a notification form and send it to the NSD so that it could check whether or not our research fulfilled the requirements of the Personal Data Act (Ministry of Justice and Public Security, 2000). We submitted three different forms, one for each of the studies.

All three studies are carried out in accordance with NSD guidance. In all three studies, we asked both the students and their parents/guardians to sign consent forms. Prior to the study, we informed the students of the purpose of the study and what the information would be used for; the methods of the study; that participation was voluntary; that the students could withdraw from the study at any time during the project; that all data would be anonymized when used in articles; that the data would be stored on secure servers; who would have access to these data; and what would happen to the data after the study was completed. I have stored the data from the Viten.no project on their original tapes in a locked closet. The data from the SCY project are stored on a secure server, as well as on external hard disks. I also keep this
external hard disk in a locked closet. In the process of transcribing the video data, I replaced all names with pseudonyms. Moreover, in coding the data from the pre- and post-tests, I replaced all students’ names with numbers. I store the key to identify the names separately from the coded data.

I faced an ethical dilemma in the process of deciding whether to use the collected data as part of my master thesis. If the data could be used, I had to ensure that their use was done in accordance with NSD’s guidelines for handling data. I knew that these data were unique and could possibly contribute to the research field; however, I also knew that NSD was in position to turn down the study if the requirements were not fulfilled. I contacted NSD, and, after several phone calls, mail exchanges, and steps, I was informed that the data could be used for my research. We also faced an ethical dilemma in the first data collection of the SCY project. After the student project was over, the teachers asked for copies of the videotapes to be used in grading the final student presentation. The students had not been informed that the data would be used in this manner; thus, based on the NSD’s guidelines, we had to tell the teachers that they were not allowed to have copies of the tapes.

However, conducting research ethically does not only involve carrying out studies in accordance with the Personal Data Act. According to Yin (2014):

A good case study researcher, like any other social scientist, will strive for the highest ethical standards while doing research. […] These also include maintaining a strong professional competence that includes keeping up with related research, ensuring accuracy, striving for credibility, and understanding and divulging the needed methodological qualifiers and limitations to one’s work. (p. 76-77)

In all three studies, I have strived for credibility and to conduct the studies ethically. The ethical principle of beneficence should also be addressed. This principle states that the risk of harm to a participant should be a minimal as possible (Brinkmann & Kvale, 2015). In general, students might experience the process of being videotaped and observed during class as intrusive. However, in all three studies (Studies I, II, and III), the students explicitly stated that they liked being part of a research project. They also signaled that they found the computer-based learning environments motivating. In Study I, there was an ethical dilemma related to the fact that one class received a treatment that led to lower learning outcomes than the other class. However, the harm to all students can be considered relatively low, since the
study lasted for only a short period of time. Thus, the value of the knowledge gained from the study can be considered to outweigh the risk of harm to the students (Brinkmann & Kvale, 2015).
6 Summary of the Studies

In this chapter, I will provide a summary of each of the three studies. The order of the articles has been chosen to exhibit an increase in number of support aspects under investigation: Study I investigates two support aspects (digital tools and peer collaboration), Study II investigates three support aspects (digital tools, peer collaboration, and instructional design), and Study III investigates all four support aspects (digital tools, peer collaboration, instructional design, and teacher intervention). However, all three articles have been produced in parallel. All articles are also written together with my three supervisors—one article with each—and I am the first author for all three articles.

6.1.1 Study I


This article reports on a comparative mixed-method study of students’ conceptual sense-making of animations versus static visualizations of protein synthesis. The aim is to provide a deeper understanding of learning potentials in settings in which students are introduced to scientific concepts embedded in animations versus static visualizations. Two research questions guides the analysis:

- How do animations compared to static visualizations improve students’ understanding of gene technology?
- How do students make sense of an animation compared to a static visualization of protein synthesis?

This study was conducted according to a socio-cultural perspective on learning. A fundamental assumption in sociocultural approach is that students’ sense-making is mediated by cultural artifacts, such as animations and static visualizations (Furberg et al., 2013; Vygotsky, 1978; Wertsch, 1991). Thus, by taking a sociocultural perspective, we attempt to understand student learning from animations and static visualizations by focusing on students’ sense-making of such representations.
In order to answer the research questions, we collected data from two lower secondary school classes working on a unit from the computer-based learning environment Viten.no. One class worked with a unit containing animations, and the other worked with the same unit, but with the animations replaced by static visualizations. The animations were designed as segmented animations, such that corresponding chunks of text appeared to explain the science displayed by each step in the animation. Further, in order to answer the research questions, we performed a two-part analysis: 1) a quantitative analysis of students’ learning outcomes by means of pre-tests and post-tests and 2) a qualitative analysis of students’ sense-making processes by means of interactional data from class and from conceptual interview conversations. We use the notion of interaction trajectory to refer to the analysis of interactions over time (Furberg & Arnseth, 2009), and we follow the interaction trajectories of two students—one from each of the two classes—while trying to make sense of the animation and the static visualization of protein synthesis.

The analysis of the pre- and post-test data shows that the students in the animated condition significantly outperformed the students in the static condition. The analysis of the interactional data (Jordan & Henderson, 1995) displays that animations are more suited than static visualizations for supporting students’ understanding of protein synthesis. Further, the analysis displays that animations stimulate conceptual sense-making and that the multifaceted interactions among the students, the segmented animation, and the text, as well as among the students themselves, stimulated the students to talk about and use scientific language to discuss protein synthesis. Most importantly, our findings suggest that animations foster the conceptual link-making and multimodal link-making (Scott et al., 2011) that take place within students’ conceptual sense-making.

6.1.2 Study II


In this study, we investigate how students work with computer simulations. In particular, we investigate students’ work within a particular technological and pedagogical design that allowed the students to compare and contrast other students’ simulation data with their own
simulation data. We use the notion of emerging learning objects (ELOs) when referring to students’ simulation data in order to emphasize that we view students’ work with computer simulations as an iterative process of testing out different parameters as they relate to simulation outcomes. The aim of the study is threefold: first, to provide insight into how students collaborate in using other students’ simulation ELOs, while refining their own ELOs; second, to explore what learning opportunities emerged from this comparison; and third, to contribute to the conceptual discussion surrounding the connection between social and cognitive processes in students’ sense-making. Three research questions guide the analysis:

- How do the students compare and contrast peer-created ELOs to refine their own ELO?
- What learning opportunities are created as a result of examining peer-created ELOs?
- How can we conceptualize the connections between social and cognitive processes in students’ sense-making?

We apply a socio-cultural perspective of learning (Linell, 1998; Vygotsky, 1986; Wertsch, 1991) and make use of a set of analytical terms developed by van de Sande and Greeno (2012) to understand students’ interactions when solving tasks. These terms include: positional framing, source, listener, conceptual framing, and alignment of conceptual framing. These concepts allow us to conceptualize the connection between social and cognitive processes in students’ sense-making. In order to answer the research questions, we performed a detailed analysis of secondary school students’ interactions (Jordan & Henderson, 1995) as they worked with a compare and contrast activity using a computer simulation on heat loss in buildings. By analyzing three excerpts from three student groups working on the compare and contrast activity, we are able to show the ways in which the students frame their tasks, as well as what learning opportunities emerge from this activity.

Our findings demonstrate that students’ work with the compare and contrast activity, as part of the pedagogical design for working with the computer simulations, created new learning opportunities for the students. These learning opportunities involved recapping earlier shared arguments, problematizing scientific questions, making sense of specific concepts, and exploring premises to compare simulation results. Our findings also demonstrate that the three student groups framed the activity differently and that specific learning opportunities were dependent on the type of framing. In addition to contributing on an empirical level, we also contribute on a theoretical level by showing how the concepts of
framing allow for the view that social and cognitive processes in students’ conceptual sense-making are intertwined, while simultaneously specifying which students contribute to interactional achievement in social activities. Based on the analysis and work of van de Sande and Greeno (2012), we develop an analytic model to illustrate how a pedagogical and technological design involving a compare and contrast activity can create new learning opportunities for students.

6.1.3 Study III


This article reports on a design study in which the role of the teacher as a facilitator in a computer-supported collaborative (CSCL) setting is investigated. In naturalistic classroom settings in which students engage with computer-supported activities, the teacher tends to represent an important resource, since he/she provides different forms of guidance during students’ learning activities. The aim of this study is to explore the concerns encountered by teachers when supporting students’ learning processes in these types of settings. The following research question guides the analysis:

- What concerns does the teacher encounter in student-teacher interaction when facilitating students’ development of conceptual understanding in CSCL settings?

In this article, we employ a socio-cultural perspective on learning (Mortimer & Scott, 2003; Vygotsky, 1978; Wertsch, 1991). According to a socio-cultural perspective, coexisting support aspects influence students’ learning processes in CSCL settings. These supports include conceptual or procedural support provided by teachers and peers, various forms of digital tools, and the overall instructional design of the student activity (Säljö, 2010). By making use of the analytical concepts of perspectival framing developed by van de Sande and Greeno’s (2012) and by focusing on teacher interventions in the intersection of digital tools, peer collaboration, and instructional design, we were able to analyze the complexity encountered by the teacher when facilitating students’ development of conceptual understanding in CSCL settings.
In order to answer the research question, we perform a detailed analysis of interactions between secondary school students and their teachers during a science project on insulation and heat transfer in low-energy buildings. We use the notion of an interaction trajectory to refer to the analysis of interactions over time (Furberg & Arnseth, 2009), and we follow the interaction trajectories of two students as they try to make sense of the concept of heat transfer coefficients in different settings. By analyzing selected chronological excerpts of the students’ interaction trajectories, we are able to show the evolving process of students’ conceptual sense-making, as well as the concerns encountered by teachers in these types of settings. The analytical method employed is interaction analysis (Jordan & Henderson, 1995).

The analyses reveal various dilemmas encountered by teachers when supporting students’ development of conceptual understanding in CSCL settings. For instance, the analysis displays that one main concern was balancing when to provide requested information and when to support students in utilizing one another’s knowledge and understanding. Another concern involved balancing support on an individual with support on a group level. Moreover, the analysis suggest that the simulation tool prompted conceptually oriented teacher-student interactions, but that the simulation tool did not in itself, provide enough conceptual support for the students to collaboratively construct a robust understanding of the concept of heat. Most importantly, the analysis display that, when something goes awry at the intersection of digital resources, peer collaboration, and instructional design, the teacher becomes the last layer of support. Further, the analysis demonstrates how teacher intervention constitutes a pivotal “glue” that enables students to link and make use of coexisting support aspects, such as digital resources, peer collaboration, and instructional design.
7 Discussion

The thesis began with two overarching aims: 1) to gain knowledge of students’ conceptual sense-making in science when working in computer-based settings and 2) to explore how support in form of digital tools, peer collaboration, instructional design, and teacher intervention can benefit students’ conceptual sense-making. In this thesis, I have explored these overarching aims. In the following, I will discuss the empirical findings for each of the four support aspects (i.e., digital tools, peer collaboration, instructional design, and teacher intervention) in light of previously conducted studies. Subsequently, I will discuss the methodological and theoretical contributions of the current thesis, before ending the thesis with a discussion of the implications of the findings.

7.1 Empirical contribution

In the following, I will account for the empirical contributions of this thesis as they relate to digital tools, peer-collaboration, instructional design, and teacher intervention.

7.1.1 Digital tools

The educational quality of digital tools embedded in computer-based learning environments needs to hold a high standard in order to effectively support students’ learning processes. Some digital tools may be superior to other digital tools in supporting students’ learning processes. A number of studies have emphasized that the quality of students’ conceptual sense-making in science affects students’ learning outcomes (Mercer et al., 2004; Scott et al., 2011); it is, therefore, of interest to investigate how different digital tools and representations impact students’ conceptual sense-making. Findings from the current thesis (Study I) demonstrate that animations support students’ conceptual sense-making in different ways than static visualizations do. The analysis of the empirical data clearly demonstrates that a multimodal representation (Ainsworth & VanLabeke, 2004) in the form of segmented animation (Spanjers et al., 2010), which displays a scientific model accompanied by explanatory text, fosters conceptual sense-making, and also conceptual link-making and multimodal link-making (Scott et al., 2011)—all of which are seen as essential elements in students’ development of conceptual understanding in science. Our analyses demonstrate that the movements in animations stimulate students to develop a mutual focus on specific aspects
of the representation—and, moreover, that students naturally comment on these movements. In the process of making sense of the movements in the animation, students make use of science concepts presented in the captions next to the animations. These findings are the result of the theoretical and analytical approach taken in the current thesis, and they clearly extend the findings from previous research on students’ learning from computer animations versus static visualizations, since the findings in the current thesis answer a different set of epistemological questions. This distinction will be further elaborated in section 7.2

Methodological and theoretical contribution. Thus, these findings are particularly interesting to this field of research because they integrate theories on the development of students’ conceptual understanding (i.e., conceptual link-making and multimodal link-making) developed by well-recognized researchers in the field of science education (Scott et al., 2011) into the field of students’ learning from animations versus static visualizations.

In the search for designs that will increase support for students’ learning processes, although it is important that digital tools embedded in computer-based learning environments have high educational quality, I will argue for the importance of focusing—not only on the design of digital tools—but also on a combination of pedagogical and technological designs. Findings from the current thesis (Study II) demonstrate that pedagogical and technological designs that enable students to compare and contrast one another’s simulation data open up new learning opportunities. These learning opportunities involve recapping earlier shared arguments, problematizing scientific questions, making sense of specific concepts, and exploring premises to compare simulation results. The implementation of a search tool supports the idea of students developing their conceptual understanding along the process of refining their ELOs, since empirical findings demonstrate that—even when students were about to complete their work with the computer simulation—new learning opportunities emerged when they were introduced to the compare and contrast activity, which stimulated them to “go another round” in refining their simulation ELO. A number of studies have demonstrated the benefit of exposing students to contrasting cases, and there seems to be consensus among researchers that contrasting cases represent an effective instructional design for student learning (Rittle-Johnson & Star, 2007; Schwartz et al., 2011). However, there also seems to be a lack of studies on students’ learning from digital tools that allow students to contrast cases. This thesis argues that there is a great potential for computer-based learning environments to support the instructional design of contrasting cases, since search tools can be implemented to enable students to search other students’ products (not only simulation
data)—and, hence, to compare their own products with peers’ products. In this sense, the thesis contributes to the field of students learning from contrasting cases, since it demonstrates how the instructional design of contrasting cases can be facilitated through the use of digital tools.

7.1.2 Peer collaboration

Supporting students’ learning processes through peer collaboration has been thoroughly investigated (Linn & Eylon, 2011; Mercer, 2004; Osborne et al., 2004; Webb et al., 2009). Previous research has demonstrated that digital tools induce communication and collaboration (Donnelly et al., 2014; Fischer et al., 2002), and several studies in the field of peer collaboration have focused on moment-to-moment interactions among students as they work with digital tools (Furberg, 2009; Ludvigsen et al., 2011). Along with the findings from these studies, the studies in the current thesis demonstrate that digital tools stimulate students to alternate in providing information necessary for the student group to develop a shared conceptual understanding of science content (Studies I, II, and III). This implies that the digital tools being investigated support peer collaboration—which, in turn, supports students’ development of conceptual understanding. However, as mentioned above, the findings in Study I concerning students’ conceptual sense-making of animations versus static visualizations clearly extend the findings of previous research, since the study demonstrates how animations evoke collaborative, conceptual sense-making differently from static representations. Study II demonstrates how the instructional design of contrasting cases evokes peer collaboration. The study demonstrates, among other things, that contrasting cases stimulate alternations in positional framing among students—which, in turn, creates learning opportunities. Hence, learning opportunities are created as a result of the “intertwinedness” of peer collaboration and instructional design. The thesis also provides another contribution related to the support aspect of peer collaboration: That is, in the field of exploring students’ intuitive ideas, most studies point to the teacher’s role in eliciting ideas from students (Harrison et al., 1999; Lewis & Linn, 1994; Schnittea & Bell, 2011). By focusing on multiple support aspects, Study III demonstrates among others that collaborative settings, when supported by an instructional design, open up possibilities for the peer-driven elicitation of intuitive ideas, without the teacher’s presence. However, the thesis also illustrates what can be seen as more challenging sides of peer collaboration. Study III demonstrates that, even when
the students were capable of exploring and addressing each other’s intuitive ideas, they found it difficult to reach acknowledged scientific ideas on their own. In addition, Study III shows that, in a group, one students’ developed understanding of a concept does not automatically ensure the development of similar understanding among the student’s peers. However, along with previous research, the study displays the significance of teacher interventions in explicating coexisting intuitive ideas and supporting students in reaching scientific solutions. As trivial as it might seem, it is of great importance that teachers prioritize spending time and effort on cultivating a classroom climate that supports critical, but constructive exchanges of ideas and knowledge through a shared conceptual sense-making. The role of the teacher will be further elaborated on in section 7.1.4, The role of the teacher.

7.1.3 Instructional design

The applied instructional design is another aspect that supports students’ conceptual sense-making. An instructional design may be facilitated through specific tools embedded in the computer-based learning environment, as in the case of Study II, in which students worked with a compare and contrast design as part of their work with the simulation tool in SCY-Lab (as described above). The instructional design may also be external to the computer-based learning environment, as in the case of Study III, which focused on the jigsaw model. In this study, the instructional design of the jigsaw model was not supported by SCY-Lab. Previous research seems to demonstrate that the contrasting cases approach is an effective instructional design for student learning (Loewenstein et al., 2003; Schwartz et al., 2011; Schwartz & Martin, 2004). However, for the jigsaw model, the findings are more divergent, in the sense that studies display both positive findings (Karacop & Doymus, 2013; Tarhan & Sesen, 2012) and equal or negative findings (Hänze & Berger, 2007; Zacharia et al., 2011) with respect to students’ academic performance. The analysis of the studies in the current thesis in relation to the compare and contrast design and the jigsaw design demonstrate that these instructional designs may support students’ conceptual sense-making by opening up new learning opportunities (Study II) or by urging ongoing, conceptually oriented peer discussions and the elicitation of ideas (Study III). However, as within any instructional design, we also found challenges related to the contrasting cases and jigsaw designs. In both designs, the analysis of students’ interactions displayed differences in students’ conceptual framings (van de Sande & Greeno, 2012)—which, in turn, impacted students’ conceptual sense-making.
Based on my approach in *Study III*, which considered the role of the support aspects of digital resources, peer collaboration, instructional design, and teacher interventions, I argue that the negative findings in previous studies related to the jigsaw model might be due to weak support from the other support aspects. This is in line with previous research, which has pointed out that the jigsaw model may be effective under certain conditions related to peer collaboration (Brown et al., 1993).

### 7.1.4 The role of the teacher

The *role of the teacher* has crucial importance in supporting students’ development of conceptual understanding. Although some existing studies focus on the role of the teacher in computer-based collaborative settings, there is a consensus among researchers that this field of research is clearly under-researched (Greiffenhagen, 2012; Urhahne et al., 2010; van Leeuwen et al., 2013). In all three studies (*Studies I, II, and III*) conducted as part of the current thesis, the teacher played an important role in supporting students’ conceptual understanding in their interactions with digital tools, as well as in organizing the students’ collaborations according to the instructional design. *Study I* demonstrate that, when the digital tool has lower educational quality (in this case, if static visualizations is used, instead of animations), students face a greater need for teacher intervention in order to develop their understanding of scientific concepts. *Studies II and III* demonstrate that students may approach tasks with different conceptual framings—and that the teacher is in the position to direct the students’ attention towards both conceptual framings, so that all students experience the same learning opportunities. *Study III*, however, takes a new approach focusing on the teacher’s role in the intersection of digital resources, peer collaboration, and instructional design. The study demonstrates that the role of the teacher in computer-based settings is very complex. In keeping with Greiffenhagen (2012), I argue that it is important to understand the role of teacher interventions in computer-based collaborative settings in order to support teachers in engaging in productive interventions in these settings. The current thesis (*Study III*) demonstrates that one concern that teachers might encounter is creating a balance between providing the requested information and supporting students in utilizing one another’s knowledge and understanding. When a teacher plans instruction involving computer-based small group settings, his intention might be for the instructional design to structure peer collaboration around digital tools. However, something might go awry in the intersection of
the three support aspects, such that the students require additional support from the teacher. Hence, it is a challenge for the teacher to know the potential limits of the different support aspects, since these might vary according to task, setting, and time. Consequently, it is also challenging for the teacher to find a balance between providing students with requested information and encouraging students to collaborate on solving problems on their own. In sum, with regard to teacher interventions, the current thesis demonstrates the significant role of the teacher in orchestrating different support aspects, as well as in supporting students’ conceptual understanding by intervening directly in student groups.

7.1.5 Digital tools, peer collaboration, instructional design, and teacher interventions

As mentioned above, the current thesis contributes knowledge concerning the complexity involved when students work collaboratively in computer-based settings, since it focuses on the multiple support aspects of digital tools, peer collaboration, instructional design, and teacher intervention. Findings from all three studies (Studies I, II, and III) in the current thesis demonstrate that students’ learning processes are intertwined with multiple support aspects. Study I focused on the support aspects of digital tools and peer collaboration, and the dual focus on these two support aspects enabled us to explore the complex interplay among the students themselves and between the students and the animation. Hence, a dual focus on digital tools and peer collaboration provided new knowledge of why animations may be superior to static visualization in supporting students’ conceptual understanding, as described above.

Study II focused on the support aspects of digital tools, peer collaboration, and instructional design, and the multiple focus on these three support aspects enabled us to explore students’ conceptual sense-making as a process interwoven with the compare and contrast activity, the simulation tool, the search tool, and students’ interactions with one another. A multiple focus on digital tools, peer collaboration, and instructional design provided new knowledge about how learning opportunities emerge, what types of learning opportunities may be created, and how students’ learning opportunities may be constrained by students’ conceptual framings of the settings involving the support aspects. Study III targeted all four support aspects (i.e., digital tools, peer collaboration, instructional design, and teacher intervention). By focusing on the teacher’s role at the intersection of these support aspects, we were able to display several concerns encountered by teacher when facilitating students’
conceptual understanding as they work in computer-based learning environments. The study demonstrated both productive and challenging sides of the support aspects—and, as mentioned above, illustrated the teacher’s challenge of knowing the potential limits of different support aspects, since these may vary across tasks, settings, and times. However, a multiple focus on all four support aspects enabled this study—before either of the two other studies in the current thesis—to display the complexity involved in supporting students’ conceptual sense-making as they work in computer-based learning environments.

7.2 Methodological and theoretical contributions

The current thesis makes several methodological and theoretical contributions to the field of student learning in computer-based settings. First, as elaborated above, the thesis contributes to the field of students’ learning in computer-based settings by focusing on multiple support aspects supporting students’ learning processes. Previous research in this field has focused on the support aspects of digital tools (Rutten, van Joolingen, & van der Veen, 2012; Smetana & Bell, 2012), peer collaboration (Howe, Duchak-Tanner, & Tolmie, 2000; Mercer, 2004), or various instructional designs (Linn & Eylon, 2011; Scardemalia & Bereiter, 2006), and most existing studies focus on the impact of only one or two of these support aspects. Since students’ learning processes in computer-based settings take place at the intersection of the support aspects of digital tools, peer collaboration, instructional design, and teacher intervention, the current thesis argues for the value of focusing analytically on all support aspects simultaneously when trying to understand students’ learning processes in these settings. Thus, in Study I, we focused on the support aspect of digital tools and peer collaboration; in Study II, we focused on digital tools, peer collaboration, and instructional design; and in Study III, we focused on digital tools, peer collaboration, instructional design, and teacher interventions. Specifically, the value of focusing on multiple support aspects is supported in Study III, in which we focused on the role of the teacher at the intersection of the other support aspects. This focus on multiple support aspects made it possible to analyze the aspects’ “intertwinedness,” which brought new insight to how we understand students’ learning processes and teachers’ interventions when students work in computer-based settings.

Second, several studies have scrutinized the moment-to-moment interactions that occur when students work collaboratively in computer-based settings (Engle & Conant, 2002;
Furberg & Ludvigsen, 2008; Jornet & Roth, 2015; Krange, 2007); however, as argued above, in the field of students’ learning from animations versus static visualizations, as well as in the field of students’ learning from computer simulations, the method of scrutinizing social interactions moment-to-moment is an under-used empirical method. By analyzing the evolving processes of student-student and student-teacher interactions, we were able to produce different types of knowledge compared to knowledge produced by more common methodological approaches (e.g., experimental approaches) that dominate the fields of students’ learning from animations and computer simulations. Although findings from experimental studies are interesting, these studies do not provide detailed information on how students work or why different experimental designs support student learning. The studies in the current thesis, in contrast, have produced this type of knowledge.

Third, another methodological contribution of the current thesis is related to the presentation of the excerpts in Study I. When students interacted with the animation on the computer screen, they often pointed to the screen to signal to one another which elements in moving model they were discussing. However, students’ collaborative sense-making of representations cannot be understood separate from the representation itself. This presents a particular challenge when the data are to be transformed from a video format (displaying both the representation and students’ interactions with the representation) to a transcribed text format and, eventually, to a representation of the model presented separate from the text. This transformation reduces the richness of the data. Gesticulations are often accounted for by descriptions of bodily movements in brackets (e.g., according to Jefferson’s (2004) notation system). However, when the model with which the students are interacting is very complex and consists of several elements (as in the case of the model of the protein synthesis investigated in Study I), and when students constantly make references to specific parts of the model in their dialogues, it is often challenging to develop a sufficient account of the interactions taking place when transforming video data into transcribed data. This challenge is related to the validity of the study, since the reader of transcribed excerpts might experience difficulties interpreting the interactions that were originally related to the transformed version of the data. Thus, in order to avoid a threat to the “validity through next turn” (Peräkylä, 2011; Sacks et al., 1974), print screens of the animated models were placed next to the students’ utterances in the excerpts, and the two types of representations (i.e., image and text) were connected with arrows. For each utterance in the excerpt that referred to a specific element in the model that was accompanied by a gesticulation on the video, we drew an arrow
from the utterance to the element in the model. I argue that this approach to presenting data increases the readability of the excerpts—which, in turn, strengthens the validity of the study.

Fourth, the current thesis contributes to the field by making use of and extending van de Sande and Greeno’s (2012) analytical framework on perspectival framing. Applying an analytical framework in different contexts validates and strengthens the robustness of the framework—and, in this sense, the current thesis makes a methodological contribution related to van de Sande and Greeno’s (2012) analytical framework on perspectival framing. Further, the current thesis extends van de Sande and Greeno’s (2012) analytical framework by arguing for the importance of expanding the analytical focus to the institutional aspect when trying to understand students’ learning processes. In contrast, van de Sande and Greeno (2012) take a situated perspective, such that they do not explicitly take the institutional aspect into account. By applying a socio-cultural perspective on learning, which accounts for the institutional aspect, we argue in Study II that we have extended and further specified the analytical stance on framing developed by van de Sande and Greeno (2012). Further, in Study II, we argue that, when we combine the analysis of conceptual and positional framing with the institutional aspect, we gain a more nuanced understanding of students’ learning processes.

Finally, the current thesis presents an analytical model of how learning opportunities are created in a specific setting. As mentioned above, several studies have provided valuable insight into students’ learning from contrasting cases (Loewenstein et al., 2003; Schwartz et al., 2011; Schwartz & Martin, 2004). Some studies have also focused on students’ learning from ELOs (de Jong et al., 2010; Hoppe et al., 2005). In Study II, we not only make an empirical contribution to the bodies of research in these two fields (i.e., students’ learning from contrasting cases and students’ learning from ELOs), but also make a theoretical contribution by proposing an analytical model for comparing and contrasting simulation ELOs to create learning opportunities. In our model, we build on van de Sande and Greeno’s (2012) concepts of framing, as well as on our empirical analysis. Specifically, in our model, we propose that (1) comparing and contrasting simulation ELOs creates (2) an engagement to improve one’s own ELO, which stimulates (3) students’ sense-making and (4) their desire to achieve a mutual understanding—which, in turn, creates (5) an alternation between the source and the listener in students’ positional framing, which, finally, creates (6) learning opportunities (all within the context that a condition for mutual understanding is the alignment of conceptual framing) (see Figure 3). We view these six steps as mechanisms that
can support students’ learning from contrasting ELOs. For a detailed description of the model, see *Study II*.

![Diagram](image)

**Figure 3:** A model of how comparing and contrasting simulation ELOs creates learning opportunities

I argue that this model is a theoretical contribution to the field of students’ learning from contrasting cases, as well as to the field of students’ learning from ELOs. However, in order to confirm the generality of the model, more research is needed on how the model can be applied to understand students’ learning opportunities when comparing their own products to other students’ products.

### 7.3 Implications of the findings

Several implications for how to support students’ conceptual sense-making in science can be drawn from the three empirical cases. The current thesis may have implications for designers who develop computer-based learning environments for use in science education. *Study I* demonstrates the value of presenting protein synthesis in the form of a segmented animation accompanied by explanatory text, compared to presenting this concept through static visualization (i.e., the representation form that is also used in textbooks). Thus, the study demonstrates that animations foster conceptual sense-making, and also conceptual link-making, and multimodal link-making. *Study II* demonstrates the value of implementing a search tool in computer-based learning environments containing simulations, since such a tool allows students to search and examine other students’ simulation data as means to refine their own simulation data. In this sense, a search tool enables teachers to choose instructional
designs related to comparing cases. Previous research has documented that compare and contrast tasks may represent an effective instructional design with regard to student learning outcomes (Baker, 2003; Jee et al., 2013; Schwartz et al., 2011). Research has also documented that students benefit from sharing knowledge online (Scardemalia & Bereiter, 2006). In light of previous research, the implications of Study II may also encourage designers to implement search tools in computer-based learning environments, thereby allowing students to produce any type of product—and not only simulation results. However, this possibility will need to be investigated in future research.

The current thesis may also inform teachers about the complexities related to supporting students’ conceptual understanding in computer-based settings, as well as the challenges inherent in balancing different aspects when supporting students in these types of settings, as displayed in Study III. Previous research has emphasized the importance of the role of the teacher in computer-supported settings (Dolonen & Ludvigsen, 2012; Greiffenhagen, 2012; Urhahne et al., 2010). However, I will argue that teachers may benefit from being informed about the complexities involved in supporting students’ conceptual understanding in these types of settings. There are challenges related to each of the support aspects of digital tools, peer collaboration, and instructional design, and I argue that teachers may benefit from heightened awareness of these challenges, for which they may then compensate by providing additional support (e.g., in the form of attention cuing, the facilitation of collaborative processes, or engagement in conceptual conversations) to directly support students’ development of conceptual understanding. In other terms, I argue that teachers’ may benefit from seeing themselves as the “glue” that enables students to link and make use of other coexisting supports, such as digital resources, peer collaboration, and instructional design. Once they are aware of their own role, teachers may be better equipped to face the challenges involved in supporting students’ conceptual sense-making in computer-supported settings.
Appendices

A. Table A: Description of data collected in the SCY project (first data collection, Study II)

B. Table B: Description of data collected in the SCY project (second data collection, Study III)

C. Table C: Description of data collected as part of the Viten.no project

Appendix A

*Table A: Description of data collected in the SCY project (first data collection, Study II)*

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video recordings of classroom interactions</td>
<td>60 hours of three student groups working on the student project (includes plenary sessions)</td>
</tr>
<tr>
<td>Pre- and post-test data</td>
<td>32 pre- and post-tests. Combination of open-ended questions and multiple-choice questions targeting students’ understanding of science knowledge</td>
</tr>
<tr>
<td>Student interviews (group)</td>
<td>Targeting students’ reflections on each of the tasks in the student project and on the overall student project, including SCY-Lab</td>
</tr>
<tr>
<td>Field notes</td>
<td>General notes from students’ work with SCY-Lab and plenary sessions</td>
</tr>
<tr>
<td>Digital products</td>
<td>Power Point presentations (students’ final presentations), digital mind maps, and digital notes from the assigned expert topics</td>
</tr>
</tbody>
</table>
## Appendix B

**Table B: Description of data collected in the SCY project (second data collection, Study III)**

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video recordings of classroom</td>
<td>60 hours of three student groups working on the student project (including plenary sessions)</td>
</tr>
<tr>
<td>interactions</td>
<td></td>
</tr>
<tr>
<td>Pre- and post-test data</td>
<td>32 pre- and post-tests. Combination of open-ended questions and multiple-choice questions targeting students’ understanding of science and mathematical knowledge</td>
</tr>
<tr>
<td>Student interviews (group)</td>
<td>Targeting students’ conceptual understanding of the expert topics, students’ understanding of the Simulation tool, and students’ reflections of the overall student project including SCY-Lab</td>
</tr>
<tr>
<td>Teacher interviews (group)</td>
<td>Targeting teachers’ views on the overall student project, including SCY-Lab, and teachers’ views on students’ achievements</td>
</tr>
<tr>
<td>Field notes</td>
<td>Specific notes from conversations in student groups and plenary sessions, with the aim of identifying hotspots</td>
</tr>
<tr>
<td>Digital products</td>
<td>Power Point presentations (students’ final presentations, teachers’ presentations, and expert’s presentation), mind maps, notes stored in SCY-Lab, and digital notes from the assigned expert topics</td>
</tr>
</tbody>
</table>
Appendix C

Table C: Description of data collected as part of the Viten.no project

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video recordings of classroom interactions</td>
<td>40 hours of eight student groups working on the student project (includes plenary sessions)</td>
</tr>
<tr>
<td>Pre- and post-test data</td>
<td>18 open-ended questions and 1 closed question targeting students’ understanding of cell biology and genetics (total of 51 student tests)</td>
</tr>
<tr>
<td>Student interviews (individual)</td>
<td>12 hours of video-recorded semi-structured post-interview conversations (12 students)</td>
</tr>
<tr>
<td>Field notes</td>
<td>General notes from students’ work with Viten.no and plenary sessions</td>
</tr>
<tr>
<td>Digital products</td>
<td>51 printouts of digital workbooks from Viten.no containing students’ answers to open-ended tasks</td>
</tr>
</tbody>
</table>
References


Zacharia, Z. C., Xenofontos, N. A., & Manoli, C. C. (2011). The effect of two different cooperative approaches on students' learning and practices within the context of
WebQuest science investigation. *Educational Technology Research Development*, 59(3), 399-424
Part II

The Studies
Study I


Science Education.
Study II

Study III

Exploring teacher intervention in the intersection of
digital resources, peer collaboration, and instructional design.
Science Education.
doi: 10.1002/sce.21181
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.

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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 (CO2) 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 CO₂ 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

<table>
<thead>
<tr>
<th>Day #</th>
<th>Organization</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>Plenary session</td>
<td>Lecture about energy supply and heat loss from low-energy buildings by visiting expert</td>
</tr>
<tr>
<td></td>
<td>Basic groups</td>
<td>Group task on concept map related to energy supply and heat loss</td>
</tr>
<tr>
<td>Day 2</td>
<td>Expert groups</td>
<td>Group 1: Heat loss and insulation</td>
</tr>
<tr>
<td></td>
<td>(Jigsaw model)</td>
<td>Group 2: Heat pumps</td>
</tr>
<tr>
<td></td>
<td>Teacher lecture in each field</td>
<td>Group 3: New renewable energy</td>
</tr>
<tr>
<td>Day 3</td>
<td>Basic groups</td>
<td>Group 4: Solar energy</td>
</tr>
<tr>
<td>Day 4 + 5 + 6</td>
<td>Basic groups</td>
<td>Peer-group presentations of individual expert fields</td>
</tr>
<tr>
<td>Day 7 + 8</td>
<td>Basic groups</td>
<td>Design and construction of virtual, CO₂-friendly house with the use of heat loss simulation tool</td>
</tr>
<tr>
<td>Day 9</td>
<td>Plenary session</td>
<td>Preparation for the group presentation</td>
</tr>
</tbody>
</table>

of the construction materials used in the virtual house model. The concepts of heat loss (J) and heat transfer coefficient (W/m²K) 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
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, CO₂-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
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/m²K). 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

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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 ((nods))

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 ((laughs)). 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.

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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 transfer coefficient,
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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

1The 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.

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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.
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

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**TABLE 4**

Excerpt 3a

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<td>1.</td>
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<td>2.</td>
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<tr>
<td>3.</td>
<td>Ali</td>
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</tr>
<tr>
<td>11.</td>
<td>Amanda</td>
</tr>
<tr>
<td>12.</td>
<td>Teacher</td>
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<tr>
<td>13.</td>
<td>Ali</td>
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<td>14.</td>
<td>Teacher</td>
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*Science Education, Vol. 00, No. 0, pp. 1–27 (2015)*
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 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.

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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 Number!
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 (Looking 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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