Instructional technologies in science education: Students' scientific reasoning in collaborative classroom activities

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INSTRUCTIONAL TECHNOLOGIES IN SCIENCE EDUCATION

Students' scientific reasoning in collaborative classroom activities

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Doctoral Dissertation

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ABSTRACT

This study originates from an interest in how students interpret scientific concepts demonstrated with animated instructional technologies. Currently, science education makes use of diverse kinds of instructional methods. For the advancement of instruction, new technologies have continuously been employed. Such new instructional technologies have always been accompanied with expectations that they should reform teaching. The availability of IT in schools and the selection of animated displays for instructional purposes provide new opportunities for education. This thesis accounts for three empirical studies of students' collaborative work with instructional technologies. For the purpose of studying students' scientific reasoning, two kinds of animated instructional technologies were designed. The three studies focused on designing and exploring the whole educational intervention and are located in the area of design-based research. They provide detailed analyses of secondary school students' collaboration on an assignment of giving a joint written account of the instructed concept. Analytically, this is done within a socio-cultural framework that uses interaction analysis inspired by ideas from conversation analysis and ethnomethodology. Study I and Study II report observations from instructional technologies that deal with the flow of materials in the carbon cycle. The two studies were connected, as the outcomes from the first study informed the educational framing of the second study. Study III reports findings from a sub-study of a design experiment where students worked in a virtual laboratory to learn about the solubility of gas in water. The results from the studies show that students' reasoning was influenced by several aspects, such as the characteristics of the animated display, language use, school cultural norms, the formulation of the assignment and the students' pre-knowledge. The analyses also evinced that the students' interpretation of a demonstrated concept often diverted from a canonical scientific one, which warns against assuming that the collaborative meaning-making of animated instructional technologies automatically leads to a creation of the desired scientific concept. These findings emphasise that when designing and applying animated instructional technologies in education, one has to consider a wider context where assignment formulation, teacher guidance, school culture and semiotic processes influence how students approach and frame their assignment.

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My grateful thoughts also go to my colleagues in the Bio-HOPE project Michael Axelsson, Maria Sunnerstam and Thommy Erissson. Thanks for the good cooperation and the many pleasant after-work sessions that generated friendships that have lasted longer than the project.

A prerequisite for the studies has been the willing participation and cooperation of management, teachers and students at the upper secondary schools where the educational interventions were implemented. All participants engaged in the educational interventions have contributed to the production of the extensive empirical material, which has been essential for conducting the analyses presented in this thesis.

My proofreader Debbie Axlid has done an excellent job with her meticulous check of my text at the very last minute.

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Göran Karlsson

CONTENTS

PREFACE

In my course of teaching science for over 20 years, I have often pondered the fact that a substantial proportion of my students do not understand the taught subject as intended. Despite having introduced a scientific concept with established teaching methods and having thoroughly penetrated the subject, subsequent tests frequently reveal that many students have not grasped the intended meaning. However, just because methods have been established and practiced for decades, they do not have to be effective. To enhance learning, the educational practice consequently has to consider new instructional methods. As Bruner (1977) reflects on aids to teaching:

> There exist devices to aid the teacher in extending the student's range of experience, in helping him to understand the underlying structure of the material he is learning, and in dramatizing the significance of what he is learning. There are also devices now being developed that can take some of the load of teaching from the teacher's shoulders. (p. 84)

I consider the study of new instructional methods to be essential for advancing science education, although new teaching techniques rely on time-consuming development for success and therefore have an obvious disadvantage compared to established methods (Bereiter, 2002). An awareness of the importance of developing and advancing instructional technologies in science education, combined with the prospects of using digital technology in this enterprise, has led me to an interest in research of computerised applications as teaching aids for the representation of scientific concepts.

Educational policy makers' thrust for *evidence-based education* calls for teaching practice to be based on the best obtainable research results (Davies, 1999). However, the idea of teaching as an evidence-based practice is called into question by, for example, Biesta (2007), who argues that eduction is "a thoroughly moral and political practice that requires continuous democratic contestation and deliberation" (p. 1). Notwithstanding, whether considered an evidence-based practice or not, all actors in the current school debate acknowledge the importance of communication between educational research and teaching practice. This need to communicate outcomes from educational research has, for example, been expressed by editors of journals of research on technology in education:

> To effectively influence practice, the results of research must also be communicated to policy makers, school board members, administrators, and teachers. Both the focus and the quality of research are irrelevant if the results are unknown to members of these important groups. (Schrum, et al., 2005, p. 207)

Accordingly, to make it possible for the school system to benefit from research results produced by the academy, there is call for a closer connection between these institutions. This realisation of a close contact between research and practice in education has not always been evident in the school debate. Instead, the link between educational research and the practice of teaching has traditionally been very weak (Lagemann, 2000).

As described by Lagemann (2000), two diametrically contradicting positions, historically and theoretically, can be discerned in attitudes towards the relation between teaching practice and the knowledge of the same. In the early nineteenth century, the debate on education in the western society was represented on the one hand by John Dewey's[1] democratic view and on the other hand by Edward Thorndike's[2] behaviouristic approach to educational practice. By defining teaching as merely a technical task, Thorndike thought teachers should come to understand their subordinate role in the educational hierarchy. In line with this, Thorndike projected a model for the educational profession presuming "that the education researcher was the searcher for truth and the practitioner was merely the person concerned with application" (Lagemann, 2000, p. 61). In contrast to this hierarchical view on teaching, Dewey (1916) in his social approach emphasised that the entire school sector including teachers, researchers and parents should participate in an intellectual debate developing the educational practice. I myself, endorsing a socio-cultural view on learning,

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1 John Dewey (1859 – 1952), an American philosopher, psychologist and educational reformer whose thoughts and ideas have been highly influential in educational systems in the United States and around the world.

2 Edward Lee Thorndike (1874 – 1949), an American psychologist whose work concerning the learning process laid the scientific foundation for modern educational psychology.

where knowledge is seen as built in interaction between humans in social activities, anticipate a development of the Swedish school system where the Deweyan democratic perspective on educational practice and research will be realised.

The close connection between practice and research, which exists in some professions, e.g. medicine, has not yet developed in education. Lagemann (2000) believes that "in part, this is because education is a field that draws on different disciplines, each of which has its own canons and conventions" (p. 240). Such a relationship can be beneficial to both the school system and the educational research community because "teaching is the central art of education [which] involves knowledge and behaviours that can be studied and improved through research" (Lagemann, 2000, p. 242). Despite the fact that educational research and educational practice have existed as two more or less separate fields for a long time, it was not until 1999 that the Swedish parliamentary appointed committee *Lärarutbildningskommittén* gave recommendations regarding the connection between teacher training programmes, educational research and the enrolment of practicing teachers in research education programmes.[3] This proposal clearly shows that the committee wishes closer connections between teacher training and teaching practice, and between educational practice and educational research. Furthermore, the committee suggested that a new area of science, *Utbildningsvetenskap* (Educational Research), should be established. Educational Research as a defined discipline has now been introduced at many universities, including the University of Gothenburg where, in September 2005, *Centrum för utbildningsvetenskap och lärarforskning* (CUL) initiated a research school for practising teachers. I was privileged to be registered in the first group of PhD students enrolled in this research school.

In light of what is said above, it is my ambition and hope that the study presented in this thesis will both contribute to the educational research field and be of interest for the practice of teaching. In my concluding remarks, I will return to some considerations about how this can be achieved.

3 Available at: (http://www.regeringen.se/sb/d/108/a/24676).

Part One

INSTRUCTIONAL TECHNOLOGIES

CHAPTER 1
INTRODUCTION

This thesis emanates from my longstanding interest in how students can develop an understanding of scientific concepts. I have also had an interest in how such development can be scaffolded by computer-based instructional technologies. Currently, education makes use of diverse kinds of instructional methods for teaching scientific concepts. For the advancement of instruction, new technologies have continuously been employed. Such implementation of new technologies for instruction in school has always been accompanied with expectations for reform of teaching through technology (e.g., Cuban, 1986). Over the last decades, we have seen the development and growth of digital technologies spreading internationally, generating such concepts as *information technology* (IT) and *information and communication technology* (ICT). These terms are also used to describe the employment of the digital technologies in educational contexts.[4]

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4 In research disciplines, labels such as *educational instruction*, *instructional design* and *instructional technology* are commonly applied for describing learning technologies. These labels are often used interchangeably (for an overview of the use of these definitions see Lowenthal & Wilson, 2010).

In the title of this treatise, I have adopted the term *instructional technologies*[5] to describe all kinds of resources included in educational instruction. Often there is a distinction made between instructional materials such as text books and technological resources such as a computer application (e.g., Krajcik, Slotta, McNeill, & Reiser, 2008). Instruction in real school practice, however, is not restricted to either kind of materials, and often includes both digital and non-digital resources. In my work I have chosen to regard all resources used for instructional purposes in education as instructional technologies, irrespective of their origin and displaying qualities.

Technological advances proffered by digital technologies have aroused a growing interest among educational researchers in technology-enhanced learning in science (e.g., Bell & Linn, 2000; De Jong, 2006; Flick & Bell, 2000; Krajcik, et al., 2008; Linn, Husic, Slotta, & Tinker, 2006; Slotta, 2004). Digital technologies are widespread and constitute an essential part of the media world, which permeates almost all of our activities. The technologies are now also available in most educational practices. Educational gains from technical innovations cannot, however, be presupposed (e.g., Ivarsson, 2004; Säljö & Linderoth, 2002). By scrutinising the relation between activities and actions performed by students who learned by means of representational technologies, Ivarsson (2004) concludes: "Given any educational material, representational technologies or otherwise, we cannot *take for granted* that pupils/students will approach them in the manner intended. Performing the (institutionally) appropriate contextualisation must be considered part of what one is supposed to learn" (p. 48). Thus, I see it essential to research how digitalised instructional technologies are used and construed by students in science education.

Computer simulations as a supportive tool for instruction have been proposed to offer enhanced discovery-based learning in which students actively discover information (De Jong, 2006; van Joolingen, de Jong, & Dimitrakopoulou, 2007). However, research results have indicated that

5 Instructional technology is defined by the Association for Educational Communications and Technology (AECT) as "the theory and practice of design, development, utilization, management, and evaluation of processes and resources for learning" (cited from AECT's website: http://www.aect.org/standards/knowledgebase.html).

students have considerable difficulties applying an appropriate inquiry process when dealing with this kind of learning applications (De Jong & van Joolingen, 1998). Therefore, most research in instructions for discovery-based learning is currently focused on finding scaffolds that might help students in their discovery process (e.g., Gijlers, Saab, & Van Joolingen, 2009; Tan, Yeo, & Lim, 2005; Vreman-de Olde & de Jong, 2006). Such scaffolds include both task-oriented instruction and explicit instruction for knowledge acquisition within the learning environment.

A variety of interactive multimedia software used for instructional purposes in science education is accessible on the Internet, on both free and commercial web sites. Notwithstanding, whether free or commercial, what all these instructional technologies seem to have in common is the scarcity of research results explaining how they function in classroom practice. As Mayer (1997) remarks for the prospects of computer-based educational technologies: "In computer-based multimedia learning environments students have the opportunity to work easily with both visual and verbal representations of complex systems, but to fruitfully develop these potential educational opportunities, research is needed in how people learn with multimedia" (p. 17). Cuban (2001) also argues that: "Without attention to the workplace conditions in which teachers labor and without respect for the expertise they bring to the task, there is little hope that new technologies will have more than a minimal impact on teaching and learning" (p. 197). In the time since Cuban's (1986, 2001) studies of computer use in classrooms, we have had many years of development for this type of instructional technology in schools. Technical innovations and new ways of working in schools have in some respect changed the conditions for the use of technologies in schools. So, for example, the expansion in the IT field has enabled new ways for collaborative work, both within classrooms and for students widely distributed. Consequently, the necessity of studying how these technologies become used and embedded in every-day school practices is an on-going task.

The study of instructional technologies can be approached from different epistemological and analytical perspectives. In order to structure the research approaches in computer-supported collaborative learning

(CSCL), Arnseth and Ludvigsen (2006) introduced a distinction between what they termed as *systemic* and *dialogic* approaches. In a systemic approach, "the task for the analyst is to describe and account for the configurations of elements that are most beneficial in terms of some outcome measure of what has been learned" (p. 170). Results emanating from such large-scale studies, concerned with learning outcomes, can generate information in terms of *what works* and *what does not work* across contexts. Systemic studies do not, however, inform about how the instructional technologies are negotiated in dialogue among the participants. To analytically make sense of this negotiating processes, Arnseth and Ludvigsen (2006) advocate a dialogic approach where "the analytical concern is with how computer applications provide a context for social interaction" (p. 174). With such an analytical approach to computer-supported collaborative learning, it would be possible to say something about *how it works* and *why it works*. Lemke (2006) also suggests that the study of learners' joint knowledge building, in connection with computer technology, requires an in-depth analysis of students' interaction with each other and the interface.

In this thesis, I am concerned with studying the students' negotiating processes in collaborative on-going activities, which are fundamentally not considered to be of a systemic nature. To capture the situated use of instructional technologies in collaborative classroom activities, I will study instructional technologies as mediating tools from a socio-cultural perspective (e.g., Säljö, 2000; Wells, 1999; Wertsch, 1991; Wertsch, del Rio, & Alvarez, 1995). From this perspective, knowledge is built in social activities and mediated through language, material artefacts and tools. In the co-evolutionary process of our acquiring of new knowledge and the production of new technologies, we continuously create representations that are essential for how we work and learn in our society. This allows for a dialogic approach where a communicative act cannot be treated as separate from other functions but instead must be related to negotiation and sense-making in a social interaction (Linell, 1998). Results from such a dialogic approach might have the potential of offering insights into processes underlying findings from systemic studies. The dialogic and socio-cultural standpoint, taken in this thesis, has consequences for both the methodological and the analytical approach – concerns that will be dealt with later on in this thesis.

The implication of studying learning from a socio-cultural perspective is that it evolves along different time-scales and across different settings (Lemke, 2000) and thus has to be studied at several levels. Ludvigsen, Lund, Rasmussen and Säljö (2011) observe that such levels of description are related, yet allow for studying different aspects of learning:

> This means, first, one can study individual learning without de-emphasizing the social and cultural aspects; second, that one can study how people learn and coordinate their activities in order to achieve a productive level of intersubjectivity and, third, that one can pay attention to how activity systems change learning at the collective as well as at the individual level. (p. 5)

This study will thus take into consideration several different aspects, such as students' orientation to the task, language use and use of resources, in the analyses of students' collaborative reasoning.

Research on instructional technologies often produces results that are not so readily adopted by the school system and not easily transformed into education. Reasons for the scarce use of research results for teaching practice might be that several of the findings emanate from short-term interventions or experimental studies, which are problematic to apply in school activities (e.g., Arnseth & Ludvigsen, 2006; Schrum, et al., 2005). Arnseth and Ludvigsen (2006) argue that the positive results from experimental studies on the use of technologies have rarely been accomplished when introduced into classroom settings. The necessity of studying how technologies are used in school activities in order to overcome the problems with experimental findings has been emphasised by educational researchers (e.g., Iding, Crosby, & Speitel, 2002; Krange & Ludvigsen, 2008; Luppinici, 2007; McCormick & Scrimshaw, 2001; Säljö, 2004). A concern for research undertaken in real school activities has also been expressed by editors of journals of educational technology (Schrum, et al., 2005). "Much of the research in educational technology (and in the field of education as a whole) has not been directly connected to schools or related to learning outcomes" (Schrum, et al., 2005, p. 204). Thus, for an informed use of instructional technologies in school practices, there is a call for studies with a high degree of ecological validity illustrating how such technologies are used in real instruction in schools. Conducting the studies in a classroom context might also contribute to the instructional technologies being appropriately assessed for educational purposes.

Since this study is guided by a research interest in the use of instructional technologies in school settings, I believe an in-depth study of learners' reasoning will give valuable contributions to the knowledge of how such technologies are exploited in science education. Hence, as my research has a practical endeavour, I consider it important to study how instructional technologies are construed and made use of in a school setting. Interaction studies as the ones presented in this thesis can hopefully produce results that can tell us about how learners construe information mediated by instructional technologies and thereby also have the potential of informing design and employment of such technologies in school activities. As expressed by Hofstein and Lunetta (2004): "In a time of increasingly rapid change in science and technology, competent teachers must continue to be informed about [...] what their students are thinking and learning in the science laboratory and classroom" (p. 48-49).

An underlying aspect of this study is to identify pedagogical potentials and shortcomings of instructional technologies in science education. The study is inspired by the assumption that the better we understand students' collaborative reasoning when working with instructional technologies, the better we can design and frame such educational interventions to support the students in reaching the learning goals. As expressed by Säljö (2004): "probing into detail about learner behaviours/activities so as to be able to provide instructional designers and software producers with appropriate models of what learners do" would imply that "the tools could be more suited to learner preferences" (p. 490).

With the organisation and research agenda applied in the studies, they can in some respect be characterised as *design experiments* (e.g., Brown, 1992). Bell, Hoardley and Linn (2004) argue that design-based research programmes in education "engineer instructional technologies including technology-enhanced learning environments and curriculum projects as well as study the educational phenomena that emerge from the enactment of the curriculum" (p. 73). Design-based research "must not only document success or failure but also focus on interactions that refine our understanding of the learning issues involved [and rely] on methods that can document and connect processes of enactment to outcomes of interest" (The Design-Based Research Collective, 2003, p. 5). The Design-Based Research Collective (2003) maintains that this kind of research can create and extend knowledge about developing, enacting and sustaining innovative learning environments: "Efforts to design, use, and do research on educational tools and materials in real settings can promote the adoption of innovations" (p. 8). In design-based research, the main emphasis is on understanding how design function and apply to complex school settings (Bannan-Ritland, 2003; The Design-Based Research Collective, 2003).

Bereiter (2002) remarks that one cannot expect immediate pay-offs from a technical innovation; new technologies have to be refined and appropriated to be able to compete against tried-out and reliable practices. According to Bereiter (2002), design-based research is therefore a prerequisite for "sustained innovation, which realises the full potential of an innovation and overcomes its original defects and limitations" (Bereiter, 2002, p. 321). Bereiter (2002) goes on to say that sustained innovative development makes it possible for educational technologies like computer simulations to survive their first failures and be driven by their potential as a learning device (p. 326).

The studies in this thesis follow trajectories of students' scientific reasoning when working with instructional technologies in science education. Instructional technologies are here perceived in a broad sense as "sources of support for learning, including support systems and instructional materials and environments" (Association for Educational Communications and Technology, 2001). The instructional technologies used in the studies include computer-animated representations of scientific concepts. Despite the notion of animation being a catch-phrase for a wide range of phenomena, the students' construal of animated instructional technologies is one of the hubs that the studies are centred around.

In the schools where the studies were performed, a regular way of organising students' exploration of instructional technologies included (1) giving the students a learning assignment, (2) students' collaborative exploration of a concept and (3) the requirement of the students to report their conclusion. Thus, the complete educational intervention with all its components has to be considered as an integrated whole in the study of instructional technologies. The instructional intervention under study is schematically outlined in Figure 1. The studies were conducted in secondary schools where science was taught, which thus constitute the learning context. Teachers in these schools are often the ones who formulate the assignment and evaluate their students' reports. The learning outcome of such an educational intervention is normally based on the teachers' evaluation of the students' (often) written reports. However, what most often remains hidden from the teacher is the process that led to the students' completed account, indicated by the dashed shape in Figure 1. Hence, the focus of my study is on students' collaborative reasoning about how to solve their assignment of discovering and writing a report on a scientific concept described in animated instructional technologies.

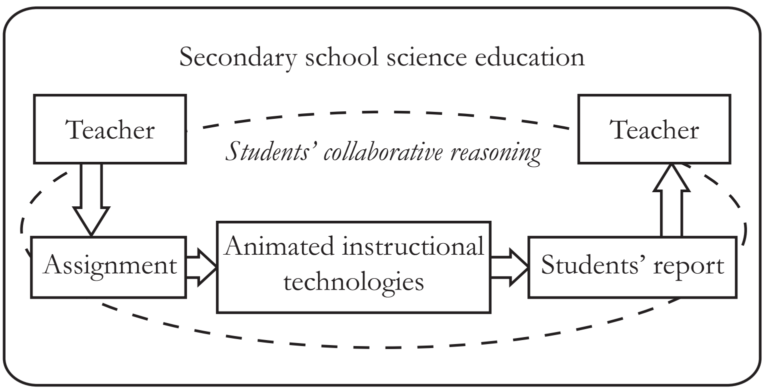

Figure 1. Schematic outline of the instructional intervention under study. The study is within the area of students' collaborative reasoning when working with the animated instructional technologies.

AIM

This thesis aims to study *students' scientific reasoning when working with instructional technologies in collaborative classroom activities*. The research perspective will be on how the instructional technologies appear from a student perspective. Results from the study are supposed to contribute to the understanding of learners' meaning-making of instructional technologies where animated representations play a prominent part. The thesis is also intended to inform design and practical use of instructional technologies in science education. The instructional technologies employed in the studies represent scientific concepts both by textual descriptions and by animations. Such demonstrations of a concept involve for the learners the reading and merging of two different semiotic resources, i.e. linguistic and visual resources. In this thesis, I report on three empirical studies conducted with the intention to present detailed analyses of students' interaction when working collaboratively with the task of interpreting and making an account of processes demonstrated in animated instructional technologies. The analytical focus is on how assignment formulation, technology, language and school norms contribute to the learners' construction of a joint description of a represented scientific concept.

RESEARCH QUESTIONS

The main question for this project has been:

- How do students collaboratively reason about scientific concepts while using instructional technologies that include animated representations?

In addition, the following three sub queries have guided the research:

- How do students approach their task?
- How do students make use of resources of different modalities?
- How can design of instructional technologies and teaching practices be informed?

OVERVIEW OF THE THESIS

This thesis consists of two parts: a cover paper, and a second part with the empirical studies. The cover paper is divided into seven chapters that cover the following themes:

In the first chapter, I give an introduction to the research field and account for my aim and research questions.

The second chapter, *Background*, reports on findings in regard to the use of animations in educational settings. Research findings concerning students' interpretation of and scientific reasoning about representations are reported. Seeing as an organised phenomenon is dealt with in relation to the participants' work of interpreting visualisations of natural phenomena.

Chapter three, *Theoretical groundings*, gives a historical epistemological outlook of various emerging perspectives on learning and knowledge. The chapter concludes with epistemological considerations pertaining to this thesis.

In Chapter four, *Research design and analytical approach*, I first give an account of the design of the instructional technologies used in the studies. My research is then located in the area of design experiments and I argue for interaction studies of collaborative learning. I deal with the problem of analysing large corpuses of data. I also describe interaction analysis, and how the studies are inspired by ideas from conversation analysis and ethnomethodology. Issues pertaining to selection of video-data and how to re-present the data are discussed.

Chapter five gives a summary of each of the three studies.

In the final chapter, the students' collaborative reasoning about what is demonstrated by the instructional technologies is discussed. In relation to the results, consequences for the design of animated instructional technologies and implications for teaching practice are also discussed. The chapter ends with some concluding remarks about aspects found to be important in the students' interpretations of instructed scientific concepts, such as assignment formulation, animacy in the representation, language use, students' pre-knowledge and school cultural norms.

The second part of the thesis comprises the empirical studies, which are presented in the following order:

Study I
Karlsson, G., & Ivarsson, J. (2008). Animations in science education. In T. Hansson (Ed.), *Handbook of research on digital information technologies: Innovations, methods, and ethical issues* (pp. 68-82). Hershey: IGI Global.

Study II
Karlsson, G. (2010). Animation and grammar in science education: Learners' construal of animated educational software. *International Journal of Computer-Supported Collaborative Learning,* 5 (2), 167-189.

Study III
Karlsson, G., Ivarsson, J & Lindström, B. (submitted 2011). Agreed discoveries: Students' negotiations in a virtual laboratory experiment. *Submitted to Instructional Science.*

CHAPTER 2
BACKGROUND

Models of unobservable scientific phenomena for educational purposes can be shaped in different ways. Educators have traditionally tackled the problem of conceptualising processes that involve invisible structures and dynamic characters by representing, for example, molecular reactions with pictorial models supplied with arrows. For example, teachers draw such sketches on whiteboards, and textbooks are equipped with pictures illustrating dynamic phenomena. Digital technologies offer enhanced opportunities to create representations of scientific phenomena that can otherwise only be demonstrated with, for example, experiments.

Static pictures give the possibility to present specific spatial configurations and indicate directions of activities, but provide no information about the course of events. Therefore, in all static models the learners have to envision the dynamics in the processes by themselves. Han and Roth (2006) identify several problems with students' understanding of textbook models illustrating gaseous states. One such problem is that whereas the main text expresses the movement of a molecule, an associated static image cannot show this movement. Another problem for students' understanding of textbook models is that gas states are described as motionless molecules distributed in empty space. Han and Roth (2006) also argue that textbook models without the possibility to show the scientific sequentiality in molecular movements may cause a contradiction between the main text and the inscription. The demonstration of such intermediate stages, showing the mechanism of molecular movements, could be "provided by a computer animation" (Han & Roth, 2006, p. 190).

Animated representations might, thus, afford possibilities to alleviate some of the problems associated with the use of static illustrations through new ways of illustrating scientific concepts. Software for producing animated displays is now available on the market and can be used by anyone interested in the production of learning material. Animated displays are able to visualise scientific phenomena and make the *unobservable observable* (Mork & Jorde, 2004). By visualising dynamic characteristics of the depicted phenomena, animated pictures in contrast to static illustrations render it possible to convey information about both spatial and temporal structures and to endow objects with characters, such as locomotive power, shifting colour, shape etc. (Han & Roth, 2006). Thus, from an educational point of view, there could be benefits from dynamical visualisation of scientific concepts in biochemical processes. Yet, like all educational tools, computer-based 3D animation brings with it certain problems (e.g., Krange & Ludvigsen, 2008; Lowe, 1999, 2003; Mayer & Moreno, 2002; Rebetez, Bétrancourt, Sangin, & Dillenbourg, 2010; Schnotz & Rasch, 2005).

The prospect of using animated multimedia presentations for learning purposes has aroused a growing interest among educators and has generated a substantial amount of research results in the field (e.g., ChanLin, 1998; Greiffenhagen & Watson, 2007; Mayer & Moreno, 2002; Rebetez, et al., 2010; Schnotz & Rasch, 2005; Tversky, Morrison, & Betrancourt, 2002). Especially in the area of science education, the potential for animation that illustrates unobservable scientific concepts has attracted researchers' attention (e.g., Hennessey et al., 2007; Kozma & Russell, 1997; Lowe, 2003; Roth, 2001; Roth, Woszczyna, & Smith, 1996). Below, I will describe research issues concerning implementation and use of animated instructional technologies in science education.

ANIMATED REPRESENTATIONS IN SCIENCE EDUCATION

Considering the outcomes of animated learning technologies in education, Mayer and Moreno (2002) recommend that instead of asking "does animation improve learning [we should ask] when and how does animation affect learning?" (p. 88). The authors recommend animation as a potentially powerful tool for multimedia designers, and they also provide research-based examples of ways in which animation can be used to promote learners' understanding of scientific concepts. However, bright their prospects for multimedia use in education, Mayer and Moreno (2002) also observe that:

> Yet, animation (and other visual forms of presentation) is not a magical panacea that automatically creates understanding. Indeed, the worldwide web and commercial software are replete with examples of glitzy animations that dazzle the eyes, but it is fair to ask whether or not they promote learner understanding that empowers the mind. (p. 97)

Animations visualising biochemical processes can be positioned into a broader classification of computer simulations defined as: "program[s] that contain a model of a system (natural or artificial, e.g., equipment), or a process" (De Jong & van Joolingen, 1998, p. 180). A general assumption is that animations enhance learning and should be the preferred mode for presenting graphics of scientific dynamic processes (e.g., Gabel, 1998; Roth, 2001; Schrum, et al., 2005; Tversky, et al., 2002). Gabel (1998), for example, argues that technologies in particular offer the possibility to help students visualise motion and structure of molecules. The computer screen as an interface is considered to provide students with a context that facilitates their mutual orientation to each other and the joint problem of making sense of scientific phenomena (Roschelle, 1992; Roth, 2001).

Research results have, however, not been able to show any consistent enhanced learning outcome brought about by the use of animations compared to static illustrations. Yet, the results in this area are inconsistent and display a complex array of out-comes that seem to depend on factors, such as the learners' pre-knowledge and the educational setting. In a comprehensive research review of animations for educational practice, Tversky, Morrison and Betrancourt (2002) could not find evidence supporting the view that animations are superior to the use of static illustrations for learning. Quite contrary to the general belief in the benefits of animations, Mayer, Hegarty, Mayer and Campbell (2005) found support for a *static-media hypothesis* in which they declare that "static media (such as static diagrams and printed text) offer cognitive processing affordances that lead to better learning (as measured by tests of retention and transfer), compared with dynamic media (such as animation and narration)" (p. 256). The authors tested this hypothesis in an experiment where groups of students learned about how every-day physical and mechanical processes worked. Students who received computer-based animation and narration were compared with groups given a lesson consisting of paper-based static diagrams and text. On a subsequent retention and transfer test, the paper group performed significantly better than the computer group. Mayer et al. (2005) conclude that this result gives no support for the superiority of dynamic media and that, instead, there is support for the static media hypothesis. Yet, Mayer et al. (2005) remark that overall, their research results "should not be taken to controvert the value of animation as an instructional aid to learning"; instead they suggest that "animations may be more effective when used to visualize processes that are not visible in the real world" (p. 264). The lack of significant results that confirm enhanced learning from animations is, however, not a sole characteristic of this learning technology but seems to be applicable to educational research in general (Berliner, 2002), and to research on technology-based learning tools in particular (for a discussion, see Russell, 1999, p. 18).

There are, however, studies demonstrating that animations might have advantages over static illustrations for certain kind of learners and learning situations (Bennett & Dwyer, 1994; ChanLin, 1998; ChanLin, 1996). ChanLin (1998), for example, compare how different visual treatments, such as no graphics, still graphics and animated graphics, influence learning for students with varying prior knowledge levels. She found that animated graphics serve as a better device for experienced learners, but not for novices. ChanLin (1998) claims that her study supports the assumption that students with different prior knowledge levels learn visual information differently, and that they therefore require different presentation forms to achieve a learning goal.

Studies on learning from animations that have compared students working individually with students working co-operatively have shown contradicting results (Rebetez, et al., 2010; Schnotz, Böckheler, & Grzondziel, 1999). When comparing individual learners with students working in pairs, Rebetez, Bétrancourt, Sangin and Dillenbourg (2010) found that learning from animation was overall beneficial to retention, but for transfer, only learners studying in dyads benefited from animations instead of static graphics. Contrary to these results, Schnotz, Böckheler and Grzondziel (1999) found that animated pictures result in better learning for individual learners but led to lower results for co-operative learning. Regarding these contradictory results, it is indicated by Rebetez et al. (2010) that one has to consider the different possibilities the students had to control the pace of the animations in the two studies. In the study by Schnotz et al. (1999), the interactive animated pictures gave students the opportunity to replay and scrutinise the animated event while in the study by Rebetez et al. (2010), the participants had no control over the presentation. Accordingly, the degree of interactivity in an animated display might play an important role for the learning outcomes.

Interactivity has been a major feature in the debate on how to advance multimedia learning technologies. The degree of interactivity ranges from low to high, depending on the type of control available to the users (Kristof & Satran, 1995). There is a general assumption – often referred to as the *interactivity effect* – that the higher the interactive level, the more learning should increase when students engage in multimedia technologies (Evans & Gibbons, 2007). Tversky et al. (2002) argue that interactivity can help learners overcome difficulties of perception and comprehension during the learning process. In line with the proposed interactivity effect, Wang, Vaughn and Liu (2011) found, when examining the impact of animation interactivity on students' learning of statistics, that increased interactivity significantly improves student achievement. However, empirical findings have not yet clearly shown the characteristics of the interactivity effect, and there are studies that do not support this argument (e.g., Boucheix & Schneider, 2009; Lowe, 1999, 2004). For example, Boucheix & Schneider (2009) showed in an experiment with an animated mechanical pulley system that the controllability of the presentation by itself was not a powerful factor in improving comprehension and could not guarantee a positive learning result. The authors, therefore, suggest that for the use of multimedia interactivity to be successful, the design of the controllability has to match the learners' processing abilities and skills.

With the rapid growth of web sites that provide animated learning technologies, and with the technical achievements in this area, we can anticipate even more refined simulations for use in science education. However, we have to take into consideration that regardless of how sophisticated these representations become, there is always an individual interpreting the depicted phenomenon based on her/his own experiences, and hence there will always be grounds for unintended interpretations (e.g., Han & Roth, 2006; Lemke, 2006; Roth, 2001; Roth, McRobbie, Lucas, & Boutonné, 1997). In consideration of several studies of animations as representational tools, Säljö (2004) concludes that:

> The modelling provided by the dynamic animation is so rich in information that it becomes difficult to discern what is to be attended to. So, the technology probably, like all other tools, is sometimes productive but sometimes not so efficient. Technology is but one element in the equation, there are many other factors such as the context, content, etc. (p. 491)

Thus, students' interpretations of an animated display is never a given. To facilitate for students to reach the learning goal, animated learning technologies might therefore gain from being supported by other educational means (e.g., Krange & Ludvigsen, 2008). In their study of how students solved a biological problem in a computer-based 3D model, Krange and Ludvigsen (2008) observed that a procedural type of problem solving tended to dominate the students' interactions while conceptual understanding of the model was only present when it was necessary to work out the problem. This tendency of making the understanding of the knowledge domain secondary to solving the problem is corroborated by several studies in the science educational field (e.g., Anderson, 2007; Lehrer & Schauble, 2006; Lindwall & Ivarsson, 2011). Therefore, Krange and Ludvigsen (2008) emphasise the importance of making the conceptual knowledge construction explicit in the educational environment and that such learning activities "always have to be supported by other kinds of interventions, such as those designed for the website or those initiated by the teacher" (p. 46).

Recommended ways to exploit animations in education have, for example, included activities that generate explanations and requesting students to answer questions during learning (Mayer, et al., 2005). To integrate and make the best use of animations in science education, Hennessey et al. (2007) propose the inclusion of instructional guidance, either written or narrative. The authors argue that the success of technology-integrated science teaching "relies on teachers *exploiting the dynamic visual representation through using the technology as a powerful, manipulable object of joint reference* – to stimulate discussion and hypothesis generation as they describe and reformulate the shared experience for students" (Hennessey, et al., 2007, p. 149).

The variety of elements influencing all kinds of learning makes it important to consider the wider educational activity, and this also applies to animated learning technologies. When studying students' interpretations of animations in science education, it is therefore necessary to consider all components of the instruction of a concept, involving actions such as the introduction of subject and the formulation of assignments given to the students. What the students make of these components, and what will be constituted in their learning outcome, can be derived from social and cultural conditions, which emphasises the need for socio-cultural analysis of instructional technologies.

To summarise, animations depicting unobservable scientific phenomena provide opportunities that static pictures do not. However, dynamic displays also entail complications when used for educational purposes. The inconsistency in research results concerning the advantages of animations in education reveals that students' interpretations of animated representations, like other instructional technologies, is not an uncomplicated task. The contradicting research results suggest that providing a truthful animated depiction of the to-be-learnt subject may not by itself be sufficient to produce the desired learning outcome. It also calls into question "a simplistic assumption that animation is intrinsically superior to static presentation" (Lowe, 2003, p. 175). It is therefore important to consider the wider learning context when researching and applying animated instructional technologies. This situation clearly shows the need to know the details about learners' interpretations of animated models of scientific concepts.

INTERPRETATION OF SCIENTIFIC MODELS

Biochemistry makes use of various symbolic representations for illustrating unobservable abstract phenomena. Such models, originally used for scientific purposes, are commonly applied as instructional tools in education, although in a somewhat adjusted form (Chittleborough, Treagust, Mamiala, & Mocerino, 2005). It has, however, been observed that students, in comparison with expert scientists, interpret symbolic representations in different ways (Grosslight, Unger, Jay, & Smith, 1991; Kozma & Russell, 1997; Rieber & Kini, 1995; Roth, et al., 1997; Snir, Smith, & Raz, 2003).

Due to insufficient prior knowledge, novices are often not capable of allocating attentional resources effectively, nor are they able to organise constituents properly to construct meaning from simulated scientific concepts (Rieber & Kini, 1995). Interviewing students about their interpretations of models of scientific concepts, Grosslight, Unger, Jay and Smith (1991) found that students were "more likely to think of models as physical copies of reality that embody different spatiotemporal perspectives than as constructed representations that may embody different theoretical perspectives" (p. 799). Kozma and Russell (1997) showed that surface features of animated chemical representations were attended to, both by experts and students, yet the difference was that while professionals focused on underlying concepts, the learners seemed to be constrained by the salient characters of the display. Findings like these imply that professionals and learners might not see the same thing in an animated display of a phenomenon. Learners lacking the necessary subject knowledge may therefore construct unintended conceptions, which are not those of canonical science. As remarked by Snir et al. (2003):

> Even though the particles of matter cannot be seen or touched at a macroscopic level, scientists assume that these particles exist and

> they become an important reality for their mind. In so doing, the science expert relates to an unseen conceptual level that is very much at odds with surface appearances. In contrast, the novice relates either to the concrete world of objects themselves or to a conceptual level that corresponds more directly to surface appearances (e.g., matter is continuous because it looks continuous). (p. 796)

This difference in experts' and novices' ways of construing scientific models thus seems to be highly dependent on the observers' pre-knowledge.

When studying learning from computer software, Roth and Lee (2006) found that "knowing about the aspect of the world, about the variables pupils investigate in school science requires learners to ontologically ground this experience of the material/social world first before they can begin making any sense of it" (p. 345). Learning from visual representations often involves the combined interpretation of a macroscopic and a microscopic world and understanding the relationship between these dimensions as well as linking an explaining text to the visualised phenomenon (Han & Roth, 2006). Students are also required to attend to some characteristics of the display but not to others and know "how the gratuitous details are eliminated" (Han & Roth, 2006, p. 178). These observations draw attention to students' various problems of conveying representations of scientific concepts into constructions that are intelligible for them.

Students' interpretation of a demonstrated scientific concept is not a straightforward quest and emerges from intertwining activities and interactions both with the social and the material world (e.g., Krange & Ludvigsen, 2008; Roth, 2001; Roth, et al., 1997). "What and how entities are salient is therefore an empirical matter" (Roth, 2001, p. 45). In his study of how students learnt to explain computer-animated events, Roth (2001) showed that animated episodes can be interpreted in multiple ways and therefore do not embed unambiguous meanings. Consequently, students' construal of computer-animated events often do not correspond with what is intended by the educator, which made Roth (2001) declare that: "Even students' perceptions of carefully staged teacher demonstrations are radically different and a function of prior expectations" (p. 50). Krange and Ludvigsen (2008) argue that when learners do not possess the specific subject knowledge, where only a small part is illustrated in the media, it "means that the students only get access to the top of the iceberg of this knowledge base, and what part of this that they manage to realise in practice is an empirical question" (p. 29). Thus, making meaning out of an illustration of a scientific concept implies that the interpreter draws on individual experiences and preconceptions, which also means that the interpretation of an illustrated phenomenon differs from reader to reader (Han & Roth, 2006; Lemke, 2006). The various interpretations that can be drawn from an animated representation of a scientific concept imply an important concern when applied for educational use.

EDUCATIONAL CONSEQUENCE OF ANIMATIONS IN SCIENCE EDUCATION

Educational problems with students' interpretations of animated representations, such as the tendency to focus on what is emphasised in the animation and drawing unintended conclusions, have been reported by, for example, Kelly and Jones (2007) and Lowe (1999, 2003, 2004). In studies on how meteorological novices worked with animated weather maps, Lowe (1999, 2003, 2004) found that much of the extracted information was driven by the objects' observability and by dynamic effects (objects moving, changing size etc.), rather than by what was thematically relevant. Retention was also higher for those aspects of the dynamic graphics that were relatively easily extracted. Lowe (1999) also revealed that lack of appropriate background knowledge of the animated phenomenon led students to impose an improper simple everyday cause-effect interpretation of the display. By allocating features in the display to *subject* and *object* roles, they tended to fall back on their everyday knowledge of a straightforward view of causality (Lowe, 1999). Furthermore, Lowe (2003) argues that students' tendency to seek cause-effect relations that make the representation more *meaningful* raises the "possibility that misconceptions can actually be induced when learners work with instructional animation" (p. 174). The risk of students coming to undesired interpretations of an animated representation was also reported in a study by Kelly and Jones (2007), where they investigated how different features of molecular animation affected students' explanations of how sodium chloride dissolves in water. From this study the authors deduce that: "Students lack the experience to understand when a perspective has been simplified for teaching purposes and may take the simplification literally and develop a misconception" (p. 428).

Students' use of everyday, non-scientific concepts – often referred to as misconceptions – and spontaneous metaphors in their reasoning about scientific phenomena should not be considered entirely detrimental for their learning. Instead, such referents in students' talk have been found to have the potential to generate and enhance conceptual learning (Hamza & Wickman, 2008; Jakobson & Wickman, 2007).

Krange and Ludvigsen (2008) showed in their study of secondary school students' interpretation of molecular representations how the computer tool mediated the students' and their teacher's talk. For example, 3D models representing molecules of amino acids were referred to as balls, a description that was followed up by the teacher. Yet, both the students and the teacher failed to explain correctly what these balls were representing. The authors conclude that it is "reasonable to claim that the 3D model comes with certain taxations, like the weaknesses concerning the conceptual representations" (p. 41). On the other hand, Krange and Ludvigsen argue that the use of everyday concepts related to the computer-based 3D model as a common reference point, even if not in a consistent manner, "indicates that the students have made parts of the knowledge domain their own" (p. 45).

The use of non-scientific and indeterminate referents observed among novices has also been demonstrated to be used by experts, such as physics scientists, when they interact in building meaning of graphical representations (Ochs, Gonzales, & Jacoby, 1996). Ochs et al. (1996) note that such indexical utterances cannot be literally understood, yet their meaning appeared to be completely unproblematic for the interlocutors. Concerning the function of such indeterminate references, they claim that: "Indeed, referential indeterminacy created through gesture, graphic representation, and talk appears to be a valuable discursive and psychological resource as scientists work through their interpretations and come to consensus regarding research findings" (p. 359).

In light of what is said above about the intricacies in, and the different ways of, talking about simulated representations of scientific phenomena, I consider the study of students' reasoning to be crucial in understanding how dynamic representations are interpreted.

SCIENTIFIC REASONING ABOUT REPRESENTATIONS

Students' scientific reasoning in connection with computer tools has been the focus of several recent studies (e.g., Ivarsson, 2010; Roth, 2001; Roth & Lee, 2006; Roth, et al., 1996). Roth (2001) showed how computer-animated events in physics education enabled students to use deictic and iconic gestures to make salient certain features to which they linked their utterances. The analyses in the study are "based on the assumption that reasoning is observable in the form of socially structured and embodied activity" (p. 34). The author argues that "when viewed against the interface as background, gestures help a speaker to make salient those aspects relevant to his or her explanation" (p. 46). In a study of an educational computer software, Ivarsson (2003) found that the reasoning performed by students and teachers could "be seen as almost two separate lines of reasoning'; however, converging in deictic expressions and actions connected to the activity, creating an 'illusory intersubjectivity" (p. 399). What made these lines of reasoning so different was that students and teachers had access to differing resources for their understanding. While the students were confined to use experiences made within the learning environment, the teachers could benefit from earlier experiences and ways of talking about the subject in other situations (Ivarsson, 2003).

Hence, when analysing the participants' interactional accomplishment of their meaning-making of events on a computer screen, the analyst has to attend to the interlocutors' multimodal actions in his or her attempts to achieve a shared understanding. The job of the analyst is then to notice and explicate the *seen but unnoticed* [6] details and interpret what is negotiated among the participants *in situ*.

6 Explicating the "seen but unnoticed" activities of social activities is a fundamental concept in ethnomethodology. For a more comprehensive account of the notion, see Lindwall (2008).

SEEING AS AN ORGANISED PHENOMENON

In everyday speech, we frequently equate the saying *to see something* with *understanding*. The concept of *seeing* is thus intimately connected to how we perceive the world. Nishizaka (2000) demonstrated the activity of *seeing* as an organised phenomenon, achieved through the precise and fine coordination of the participants' conduct. In two such distinctly dissimilar activities as joint playing of a computer game and a lesson with a learner and an instructor in front of a computer screen, it was shown how the participants organised their activity of seeing interactively and sequentially. According to Nishizaka (2000), "seeing is a public and normative phenomenon, which is achieved in and through the actual course of a distinct activity" (p. 120). Objects on the monitor were shown to have their visibility embodied in the actual arrangement of participants' bodies and conducts in an on-going activity (Nishizaka, 2000). Consequently, the author emphasises that analysts should not presuppose that there are human beings on the one hand and artefacts on the other and then try to explore the interactions of these entities; instead together with human bodies, artefacts, talk and other types of conduct constitute an entire *activity system*. Nishizaka (2000) concludes: "Seeing is not a processing of information that comes from objects in the outer world into the human body, but a structural feature of an activity system" (p. 122).

Mondada (2003) demonstrated different practices of seeing in surgical work, such as *professional vision* and *instructed vision*. In her study, a video recording of surgical work was transmitted to screens both for an operating team and for a distant audience. It was revealed how an utterance such as "you see" by the surgeon prefaced the accomplishment of the visibility for the audience during the demonstration and thus was accounted for as a kind of instructed vision. This instructed vision was orchestrated by descriptive and pointing activities of the demonstrating surgeon and involved considerable movements in the camera work. Conversely, professional vision for the purpose of the operating team demanded a more stable camera view. Mondada argues that these different practices of *seeing*, involving coordinated actions, gestures, talk-in-interaction and image manipulation, facilitated both for the professional vision for the operating team and for the instructed vision for the audience.

In another study, focusing on multimodal resources by which participants make their orientations publicly visible to each other, Mondada (2006) demonstrated the ways in which these resources can be documented in an analysis. This was made by approaching the phenomenon of the practices by which participants projects the end of the turn and the closing of the sequence.[7] The study analysed video fragments from a meeting in an architect's office with three people working on a building project. The analysis focused on the participants' problems with producing the recognisable nature of their actions. As an example of this, it is shown how one of the participants tries three times to initiate the closing of an activity phase, but is each time blocked in his projection by another participant. This is made visible not just by the sequential organisation of talk-in-interaction, but also by the organisation of the local space, populated with artefacts and configured by the participants' gestures and body movements. The members' problem of documenting the recognisable nature in the participants' actions is also the problem for the analyst and depends crucially on "the kind of data the analyst is able to produce [and] on the way in which temporality and deployment of actions are transcribed and represented" (Mondada 2006, p. 127).

This chapter has pointed to the inconsistency in research results concerning the advantages of applying animations in education. The literature review reveals the complexity of learning from representational media where varying aspects, such as the learners' previous knowledge and the educational setting, might have consequences for how animated instructional technologies will be understood. Identifying what is behind the variation in learning outcomes, calls for a research approach that tells us about the details of learners' interpretation of instructional technolo-

7 A model for turn-taking in conversation is proposed by Sacks, Schegloff and Jefferson (1974). In this organisation of talk-in-interaction, participants display their orientation to unfolding, emerging, dynamic details that are dealt with, allowing the participants to predict points of possible completion where a unit is likely to end.

gies. In this thesis, I have therefore studied students' scientific reasoning in collaborative settings. This research approach is theoretically anchored in a socio-cultural epistemology, where I study what happens while a group of learners solve the problem of interpreting scientific concepts described in animated instructional technologies.

CHAPTER 3

THEORETICAL GROUNDINGS

Some of the most fundamental issues in educational research have been epistemological, i.e. how learning is accomplished and knowledge is constructed. Insights into these processes might provide us with the means to design educational activities in ways that foster an intended learning outcome. In this chapter, I will give a background of the theory of learning and knowledge, and then a brief account of the epistemological considerations.

NATURE OF LEARNING AND KNOWLEDGE

Attempts to understand the nature of human knowledge go back to ancient Greek philosophers, such as Plato and Aristotle. Until the 19th century when experimental psychology developed, the question of learning and knowledge belonged in the realm of philosophy. The German physician and psychologist Wilhelm Wundt (1832-1920) is known as the founder of experimental psychology and as the first establisher of a psychology laboratory.

In the first part of the 20th century, the the psychological perspective on learning became dominated by a paradigm referred to as *behaviourism*. Analytically, behaviourism has its roots in *logical positivism*, which proposes that the meaning of statements, scientific or philosophic, should be empirically verified by observations and experimental conditions (Smith, 1986). This unification of the analytical perspective in psychology with natural science led to the behaviouristic view that psychology is an objective experimental branch of natural science, whose theoretical goal is the prediction of a reaction given the stimulus. The behaviouristic theory thus offers a way to approach the field of psychology with scientific methods.

Behaviourism studies activities such as acting and thinking performed by organisms (including humans). It purports that psychology should not concern itself with mental states or events, or with constructing internal information processing accounts of behaviour, but instead explain behaviour in terms of external physical stimuli, responses, learning histories, and reinforcements. According to the behaviouristic theory, references to mental states, such as beliefs or desires, add nothing to what psychology can, and should, understand about the sources of behaviour. Mental states are seen as private entities that do not form proper objects of study for a scientific analysis. The behaviour of a person is not accounted for by referring to inner cognitive capacity. Behaviourists' objection to internal cognitive activities "is not that they do not exist, but that they are not relevant in a functional analysis" (Skinner, 1953, p. 35). Since the existence of a mind, and the act of learning and knowing, could not be proved from observation of behaviour, behaviourists allege that "it makes more sense to talk about neurological structures or about overt behaviours than about ideas, concept or rules" (Gardner, 1987, p. 39). Psychological behaviourism is present in the work of, for example, the Russian physiologist Ivan Pavlov (1849–1936) and the American educational psychologist Edward Thorndike (1874–1949). Yet, behaviourism is mainly associated with the research of the American psychologist B. F. Skinner. In his analysis of speech, Skinner (1957) accounts for the objective dimensions of verbal behaviour as the speaker's current motivational state, current stimulus circumstances, past reinforcements and genetic constitution. Skinner thereby invokes objective non-mental entities to account for language acquisition.

By the mid-20th century, the impact of the behaviourist theories in the study of human learning and knowing was approaching an end and a more mentalistic view, which acknowledged the mind in our realisation of the world and how we acquire our knowledge of the same, emerged. In a review of Skinner's book on verbal behaviour, Chomsky (1959) rejected the behaviourist assumptions about language as a learned habit and maintained that the behaviourist models of language learning cannot explain various facts about language acquisition, such as the rapid acquisition of language by young children. Chomsky argued that it does not seem to be the case that language learning depends on reinforcement, and instead proposed the hypothesis that the psychological principles underlying language development are innate, abstract entities that apply to all languages. The problem of behavioural competence and thus performance, to which Chomsky referred, goes beyond language learning by young children, and his argumentation therefore became a major critique of behaviourism. Many critics of behaviourism claim that it appears to be a fundamental fact that human capacities often surpass the limitations of individual reinforcement histories and that much learning, consequently, seems to be dependent on the individuals' learning history and pre-existing representations. This implies that behaviourism is too limited regarding the role of brain mechanisms in producing and controlling behaviour. For the critics of behaviourism, the brain should not be seen as a mere passive memory bank of behaviour (e.g., Roediger & Goff, 1998), but instead as an active interpreter that is able to control and perform tasks. The educational research then began to change direction to a more cognitively oriented perspective that was interested in the study of mind and intelligence. This *cognitive science* was based on the hypothesis that thinking can best be understood in terms of mental representations and computational procedures that operate on those representations.

In the late 1960s, science education research was essentially focused on cognitive structures or cognitive operations performed by the individual learner – inspired by Piaget's idea of intellectual development – even though the research was still influenced by behaviourism (Duit & Treagust, 1998). In the 1970s ideas emerged that learning was dependent on a framework of specific concepts and the integration between these concepts. Drawing on Ausubel's (1968) theory of meaningful learning, Novak (1978) argued that "concepts function to facilitate learning only when they are relevant to the new learning, and similarly they function in reasoning or problem solving only to the extent that they render interpretable the regularities in the tasks" (p. 474). Throughout the 1980s and 1990s, theories about learners' engagement and their role as constructors of their own knowledge emerged and appeared as variants of *constructivism*. It is in the field of science education that the ideas of constructivism have had their most profound influence – they were widely accepted and still represent the dominant perspective (Sjøberg, 2010).

CONSTRUCTIVISTIC PERSPECTIVES ON LEARNING

The constructivistic school of knowledge-building rests on the legacy of the Swiss biologist and developmental psychologist Jean Piaget. He showed that children of different ages in childhood construct and develop certain concepts about phenomena surrounding them (Piaget, 1929/1975). Piaget's research concentrated on the individual's gradual intellectual development, a process often described as his *stage theory*. Although Piaget's interest was not primarily in education, let alone teaching, his ideas came into prominence in theories of learning in mathematics and science from the late 1960s. The Piagetian perspective of constructivism is often referred to as *cognitive constructivism*.

With a standpoint in Piaget's cognitive developmental theory, von Glasersfeld (1995) formulated fundamental principles for what he described as *radical constructivism*. Von Glasersfeld emphasised that radical constructivism is a thoroughly instrumentalist theory that rejects any metaphysical claim. He declares that the concepts we construct for describing e.g. time, space and reality are just instruments that we use to organise our experiences, but cannot be said to represent an ontological reality. An existing real world is neither presupposed nor denied, but since the only representation we can obtain of the world is created in our mind, through our senses, it is only that picture we can study. Von Glasersfeld argues that we cannot gain knowledge about the world as it really is, since the only means we have to observe the world is though our senses. The radical constructivism is therefore not about what really exists or not, but about how we build up our conceptual structures.

In addition to the individualistic perspectives on how knowledge is constructed, social and cultural conditions for learning have been increasingly acknowledged. Such a social approach is often referred to as *social constructivism* (e.g., Alexander, 2007; Duit & Treagust, 1998; Roschelle, 1992; Sjøberg, 2010). Thus, from the core constructivistic assumption that knowledge cannot be transmitted from one individual to another, there has been a growing emphasis on the interplay among various social and cultural factors for the construction of knowledge (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Hennessey, 1993; Roth, 1995).

The term *constructivism* is now used in various versions that represent the current wide range of different aspects within this dominating field in science education. With its broad set of ideas, it is debated whether the constructivistic perspective can still be said to represent a *paradigm*[8] in science education (e.g., Solomon, 1994). To account for the wide range of constructivistic notions, the term *research programme* has instead been suggested (e.g., Sjøberg, 2010; Taber, 2006). A research programme offers heuristic guidance to researchers within the field and denotes a set of ideas that provide a platform of common assumptions about certain phenomena (Lakatos, 1970). Taber (2006) describes the currant commitment for the constructivistic research programmes in science education:

> The active role of the learner is still a cornerstone of research, but 'construction' is perhaps just one useful descriptor: learning is also *contingent* (upon the cognitive resources available, on the teaching provided, on the ideas triggered through student dialogue), and so the new *connections* made are *constrained* and *channelled*. Understanding *learning in science* requires research into the contingencies that constrain and channel the connections made during the construction process. (p. 173)

However, the constructivistic perspective on learning and its consequences for teaching methods have been criticised. For example, some disagree with

8 Kuhn (1970) defined a scientific paradigm as what members of a scientific community, and they alone, share.

the constructivist argument for unguided or minimally guided instruction in teaching, and argue that instructional guidance should provide information that fully explains the concepts and the procedures that students are required to learn (e.g., Kirschner, Sweller, & Clark, 2006; Klahr & Nigam, 2004; Mayer, 2004; Sweller, 2004). From this standpoint it is argued that while the constructivistic description of learning might be accurate, it does not automatically lead to a prescriptive teaching technique (e.g., Clark & Estes, 1998; Kirschner, Martens, & Strijbos, 2004; Kyle, 1980).

Kyle (1980), for example, makes a clear distinction between scientific inquiry and inquiry in general and argues that:

> [S]cientific inquiry is a systematic and investigative performance ability, which incorporates unrestrained inductive thinking capabilities after a person has acquired a broad and critical knowledge of the particular subject matter through formal learning processes [and that] students should not be led to believe that they are performing scientific inquiry when in fact they are learning. (p. 123)

Kirschner et al. (2006) remark that the critique against constructivistic instructional methods is that it equates the way an expert works in the domain with the way one learns in the area, and state that "the epistemology of a discipline should not be confused with a pedagogy for teaching or learning it. The practice of a profession is not the same as learning to practice the profession" (p. 83).

Despite this criticism, the idea of constructivistic teaching, broadly conceived yet conceptualised in different versions, currently appears to be the predominant theory in science education (Sjøberg, 2010). The principle that learners have to construct their knowledge, rather than receive it in a ready-made package, entails profound implications for the organising of institutionalised education.

A SOCIO-CULTURAL PERSPECTIVE

Since the end of the 20th century, we have seen the rise of a *socio-cultural* perspective on learning and knowledge. In this theoretical framework, learning is assumed to take place when humans participate in cultural activities. When we interactively engage in such activities, we use intellectual and physical tools in which our cultural knowledge is embedded (e.g., Säljö, 2004; Wells, 1999; Wertsch, 1991; Wertsch, et al., 1995; Vygotsky, 1930/1978, 1934/1986).

The importance of social interaction and cultural conditions for learning has been inspired by the work of the Soviet psychologist Lev Vygotsky. Vygotsky (1934/1986) emphasised the importance of language and thinking for our knowledge building, two factors he described as developing mutually, even if not always running parallel. The act of thinking is by Vygotsky perceived as a form of *inner speech*, developed from the child's external speech. The connection between a child's linguistic development and the development of the mind is one of Vygotsky's most important pedagogical contributions. Vygotsky argued that conceptual development takes place in close connection with education and learning processes, which contrasts Piaget's view that learning and psychological development are two independent processes. According to Vygotsky, education has to support functions that are maturing, and builds on the foundation that the child learns through imitation, collaboration and adult guidance. These functions are in the *zone of proximal development* (ZPD), which is defined as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1930/1978, p. 86). Vygotsky rejected the dichotomy between the internal and the external, and central in his thinking was to overcome the dualism that separated the individual from the practices humans take part in (John-Steiner & Mahn, 1996). Vygotsky was committed to reformulating an alternative to psychology, rooted in the philosophical tradition of Marxism (dialectical and historical materialism), that could better assist society in the emerging Soviet Union (Wertsch, 1985; Wertsch, et al., 1995). Much of the theoretical underpinnings for the socio-cultural-historical approach originate from the ideas of Vygotsky (John-Steiner & Mahn, 1996).

The socio-cultural perspective can be exemplified by Bruner's (1996) account of two strikingly divergent concepts describing the function of our mind and how it might be cultivated through education. The first of these two models is based on the hypothesis that our mind can be conceived of as a computational device, which is primarily concerned with processing unambiguous information taken as given and already settled in relation to a pre-existing world. Bruner (1996) does not reject this *information processing* theory although he questions whether it offers an adequate enough observation of how our mind works and concludes that the human intellect is not independent of our culture and accessible devices, "for in certain respects, 'how the mind works' is itself dependent on the tools at its disposal" (p. 2). By this statement, Bruner connects to the nature of the human mind, which takes its stance in the evolutionary fact that the human mind is linked to the development of our culture. Culture is here represented by a symbolism that is shared by members of a community and is elaborated on and passed on to succeeding generations. This symbolic mode, although shared by members of the culture, is shaped in the mind of the individual, which "inheres in *meaning making,* assigning meanings to things in different settings on particular occasions" (Bruner, 1996, p. 3). Consequently, it is our culture with its possibilities of inventing, creating, tool-using and communicative resources that builds the foundation for developing and maintaining knowledge. In this view, "learning and thinking are always *situated* in a cultural setting and always dependent upon the utilization of cultural resources" (Bruner, 1996, p. 4). This way of situating meaning-making processes in their cultural context clearly adheres to the epistemological socio-cultural approach where learning and knowledge are mediated by tools and situated in a social practice (e.g., Säljö, 1998; Wertsch, 1991).

In a socio-cultural approach the *situated perspective* of learning is emphasised, and learning is seen as a process of enculturation into a community of practice and discourse (e.g., Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). The situatedness of knowledge implies that perception is partly a product of the activity, context and culture in which it is developed (Brown, et al., 1989). The concept of situated cognition also implies that "cognition, including thinking, knowing, and learning, can be considered as a relation involving an agent in a situation, rather than as an activity in an individual's mind" (Greeno, 1989, p. 135). "It [educational research] is sociological and ethnographic in the main, with a strong attachments to philosophies of action, natural language and social science" (Macbeth, 2011, p. 74). Lave and Wenger (1991) formulated a theory about how learning and knowledge are situated in social interactions when we engage in social activities. The process of learning, viewed as a situated activity where learners participate in communities of practitioners, is by Lave and Wenger (1991) given the locution *legitimate peripheral participation* (LPP). They emphasise that learning through LPP "takes place no matter which educational form provides a context for learning, or whether there is any intentional instruction" (p. 40). According to Lave and Wenger (1991), LPP is not to be seen as an educational form or a teaching technique, but rather as an analytical perspective and a way of understanding the mechanism of learning.

Distinguishing between learning in communities of practice and institutionalised education can be problematic since methods of instruction vary between different settings. Also, there is a clear connection between learning in practice and instrumentalised learning (Vann & Bowker, 2001), since the institutionalised learning in schools can be said to constitute a social practice in itself. Analytically, the study of situated action warrants its findings empirically in the detailed study of actual cases and their reproducibility in subsequent cases, rather than in "process-product or central tendency models" (Macbeth, 2011, p. 77).

EPISTEMOLOGICAL CONSIDERATIONS

We have thus seen an epistemological shift in focus from what might be taking place in *the heads of* individual learners, often referred to as the *cognitive approach,* to what is taking place *between and among learners* in interaction, which is focused on in the *socio-cultural approach*. This move towards the group as the unit of analysis is inspired by the social theory of mind, outlined by Vygotsky (1930/1978). Although there has been, and still exists, a tension between stakeholders of different epistemological stances, there are also attempts to integrate cognitive and social dimensions in learning theories (e.g., Billett, 1996; Greeno, 2011; Greeno & van de Sande, 2007; Murphy, 2007; Sfard, 1998). Greeno (2011), for example, proposes an integration of cognitive science and situated analysis to develop a theory of cognition and learning "that is primarily about interaction in activity systems, and includes analyses of structures of information that the participants have in common ground and generate in their activities of accomplishing tasks" (p. 43).

Especially in the research area of *conceptual change*, there has been a debate between the cognitive and situated (or socio-cultural) perspective over the theorising about learning and instruction (Vosniadou, 2007). The notion of conceptual change can be defined as "the problem of how concepts change with learning and development" (Vosniadou, 2007, p. 55). Conceptual change is often described as the process through which students modify their existing understandings about the natural world towards more scientifically held understandings regarding natural phenomena (e.g., Hayes, Goodhew, Heit, & Gillan, 2003). This notion of conceptual change has often been referred to as a cognitive research agenda (Murphy, 2007). From a cognitive perspective, the concern is not so much about the students' understandings, but rather to what extent they change their existing conceptions to align with scientifically held concepts. However, this does not mean that socio-cultural researchers, in the field of science education, are not interested in this direction of change, but rather that "they see the mechanisms of such change lying more in the social elaboration, sharing, and conflict of ideas rather than being mainly dependent on individual experience" (Mercer, 2007, p. 76). As remarked by Lemke (2001), a socio-cultural view on science education does not entail a denial of cognitive dimensions and change of learners' minds, but instead we should recognise that such changes involve social processes and membership in "particular subcultures and its system of beliefs and values" (p. 312).

It is obvious that there are different epistemological assumptions grounding these perspectives, yet many connections can also be discerned. For example, the idea of situated cognition, which is a central concept in socio-cultural theories, also plays a key role in socio-constructivist approaches employed in science education (e.g., Hennessey, 1993; Roth, 1995, 2001).

Duffy and Jonassen (1992) note that our theories of learning and design of instruction in education must go hand in hand as our artefacts clearly reflect our theory. Fundamental principles for such instructional technologies that acknowledge the social constructivist concept of knowledge as individually and co-constructed "should consist of experiences that facilitate knowledge construction" (Jonassen, 1999, p. 217). Jonassen (1999) furthermore emphasises the potential of technology to engage learners in "cooperative learning, where they collaborate with each other and socially negotiate the meanings they have constructed" (p. 218). To support and engage learners in such social knowledge construction, Jonassen (2004, 1999) suggests the designing of *constructivist learning environments* (CLEs). Such CLEs should give students access to knowledge-building tools, encourage conversations about the problems the students are working on, and thereby facilitate for learners to collaboratively construct knowledge. By creating CLEs, Jonassen (1999) argues that we engage students in "conceptual and strategic thinking, in contrast to reproductive learning" (p. 286).

The prospects for the digital technology to create learning materials that draw on constructivistic theories have been described by Petraglia (1998):

> The process of integrating constructivism into educational practice is clearly mirrored in the field of educational technology which, like education generally, draws on constructivist theories of learning to justify pedagogical innovations that encourage "everyday thinking" within "authentic" tasks in an attempt to situate learning. (p. 5)

Petraglia here accentuates what he implies are many educators' and technologists' hopes for the digital technology to "bring authentic learning materials and environments into the classroom" (p. 5). It is a common argument that such authentic tasks can be applied in school activities and thereby have the potential to provide learners with thought-provoking problems in order to stimulate their construction of knowledge (Petraglia 1998). With the notion of *authentic* tasks, Petraglia refers to real-world experiences that occur outside a school context in our everyday lives. However, in a situated perspective, learning is seen as an activity occurring in every situation where people engage in activities (Lave & Wenger, 1991). Thus, learning accruing from institutionalised education in classrooms is here viewed as authentic in the same sense as learning taking place in all learning situations.

The instructional technologies designed for the studies were intended to enable the students to engage in collaborative knowledge construction of the to-be-learnt concept (Jonassen, 2004, 1999). In their work with the instructional technologies, the students are supposed to discover the desired learning outcome, which means that the method can be classified as a discovery (or guided-inquiry) instructional style (Domin, 1999). This method of engaging students in the discovery of scientific concepts by using simulations has been proposed to enhance learning (De Jong, 2006; van Joolingen, et al., 2007). To overcome the problems for students to discover the intended scientific concept in this kind of instructional technologies, scaffolds that aim at supporting the discovery learning process are recommended (e.g., Gijlers, et al., 2009; Vreman-de Olde & de Jong, 2006). Thus, the animated instructional technologies were facilitated with several scaffolds (e.g. study questions, assignment boxes and instructional texts) to encourage students to collaboratively construct a scientific concept.

Studies of instructional technologies from cognitive and constructivistic perspectives usually concentrate on individual performances and outcomes from learning activities. However, the socio-cultural focus on knowledge as distributed and socially constructed, taken in this thesis, calls for another set of empirical studies. In a socio-cultural analysis, a common unit of analysis is the collaborating group where participants in their interaction with each other and with cultural tools display understanding for each other (e.g., Crook, 1994; Säljö, 1998; Wertsch, 1991).

The socio-cultural perspective implies that the cultural context where the learning takes place is of fundamental importance in the processes of knowledge production. Learning in school activities should then be considered to be a special kind of social practice. When studying learning in school activities, I thus agree with Lave and Wenger's (1991) view that "analysis of school learning as situated requires a multi-layered view of how knowing and learning are part of social practice" (p. 40). The socio-cultural perspective allows for an analysis of collaborative learning where students interact with each other and with various physical tools. Learning is seen as mediated through the use of tools in relation to how the students participate in the practice of interpreting and constructing a shared meaning of instructed concepts. In line with the concept of mediation by technology in teaching and learning, the instructional technologies used in the studies are seen as tools, mediating certain scientific concepts in the students' reasoning about the subject (Säljö, 1998, 2004; Wertsch, 1991). The empirical material underlying the analyses is based on video data where students interact with each other and technological tools. Thus, the analyses of the students' work consider social as well as contextual factors that influence their reasoning when working with the instructional technologies. Accordingly, the analytical focus in this study is not on the instructional technologies, as such, but instead on how these are used and construed by the learners.

Throughout this chapter I have briefly accounted for different epistemological perspectives and the theories behind them. The differences and the tensions, but also the connections, between these perspectives have been made evident. Despite the complications and critique of constructivistic teaching methods accounted for above, such methods are predominant in the Swedish national science curriculum. The instructional technologies developed for the studies were designed to fit into the curriculum and can thus be positioned in a prevalent socio-constructivist tradition of teaching in science education. My analytical focus is, however, based on a socio-cultural framework where learning and knowledge building is seen as a social and situated process that is mediated by tools.

CHAPTER 4

RESEARCH DESIGN AND ANALYTICAL APPROACH

The three empirical studies comprise investigations of students' interaction with each other and with instructional technologies. They present analyses of students' meaning-making of animated instructional technologies. The instructional technologies were used as an integral part of an educational intervention. Here, I will first give an account of the design of the instructional technologies applied in the studies. I will then describe aspects pertaining to my analytical interests, here identified as *studies of interaction, collaborative learning, assignment formulation and construction of a linguistic account*.

DESIGN OF THE INSTRUCTIONAL TECHNOLOGIES

Two kinds of instructional technologies were created and studied *in situ* as an integral part of a lesson plan. They were both designed in line with a socio-constructivist learning approach where knowledge is seen as built up by individuals from their mutual experiences and modified in social interaction. The instructional interventions were structured in a way that required the students to give joint written replies to questions about the represented scientific concept. These written accounts were assessed by the teachers, and then the students' reports and the teachers' assessments were collected for research purposes.

Study I and Study II report observations from instructional technologies that deals with the flow of materials in the carbon cycle.[9] The learning software is furnished with animations complemented with explanatory texts to facilitate for the students to get an understanding of what is happening in the animated processes. Each of the processes within the carbon cycle (photosynthesis, combustion and mouldering) is equipped with educational texts and accompanying pictures that link to animated sequences depicting the exchange of gas molecules between the organism and its surrounding. To make the illustrations as uncomplicated and concrete as possible, just one process is visualised in each sequence. The explanatory texts are also shaped to be as clear and concise as possible, excluding irrelevant words and structures. Thus, each page is captioned with an explanatory text and a miniature image underneath linking to an animated sequence of the described process of photosynthesis, breathing, combustion and mouldering. The instructional technologies were enacted in two successive interventions.

Study III reports findings from a study of students' work in a virtual laboratory.[10] In this virtual laboratory, the students in different experiments have to find out about the solubility of gas in water. These virtual experiments were developed to allow for students to examine gas solubility in water and how it varies with environmental conditions, such as temperature, salinity and air pressure. An ambition was to design a computer simulation that is well suited for discovery learning where the main task for learners is to "infer, through experimentation, characteristics of the model underlying the simulation" (De Jong & van Joolingen, 1998, p. 179). Thus, the intention was to make the virtual experimentation function like traditional laboratory work. Instructive guidance for the students' laboratory work is incorporated in the form of both a folding menu and pop-up

9 Available at: http://www.init.ituniv.se/~gorkar/.

10 Available at: http://esi.stanford.edu/gasesinwater/gasesinwater15.htm.

boxes. This virtual laboratory was developed in three different versions during the iterative processes of design and enactment.

With the intention of doing design-based research, both researchers and teachers were involved in the design process of the instructional technologies. The preparation and redesigning of the instructional technologies were discussed and planned together with the teachers involved. In the design process of the instructional technologies demonstrating the carbon cycle, I was the only researcher involved together with three teachers. The other instructional technologies were produced in a collaborative research project between the University of Gothenburg, Chalmers University of Technology, Stanford University and Linköping University involving researchers and teachers from both Sweden and California. The students' work was documented in several ways: through field notes, video recordings of groups working with the learning technologies, students' written accounts of their assignment and interviews with teachers and students. Results from analyses of the data were discussed with involved researchers and teachers. Outcomes from these discussions then formed the basis for modifications of the instructional technologies for further interventions.

An organisation of the studies as described above allows for the studies to, in some respect, be described as *design experiments* (e.g., Bannan-Ritland, 2003; Bell, et al., 2004; Brown, 1992; The Design-Based Research Collective, 2003). Design-based research methods focus on designing and exploring the whole educational intervention. This includes artefacts and activity structures for understanding the relationships between designed artefacts and practice (The Design-Based Research Collective, 2003). In design research, it is not just the utilised technology-based tool itself but also how it is used in its social context that is important to study (Bielaczyc, 2006). A variety of methods are employed in design-based research. In my studies, I have used detailed analyses of student interactions as it enables for an insight into students' construal of the instructional technologies.

Science education research has mainly focused on what might be sufficient conditions for students to be capable of giving a scientific account of a demonstrated natural phenomenon. However, a growing realisation has emerged that there is a need also for interaction studies that give information about learners' meaning-making of a represented phenomenon and the process of concept building based on instructional technologies (e.g., Erickson, 2006; Hamza & Wickman, 2009; Kelly & Crawford, 1997; Kelly & Jones, 2007; Lemke, 2006; Roschelle, 1992; Scott, Asoko, & Leach, 2007).

According to Erickson (2006), "There is an interactional turn in educational research; a recognition that research phenomena of substantive and policy interest are interactionally constituted" (p. 177). Scott, Asoko and Leach (2007) stated that although educational researchers now have extensive knowledge about students' science concept learning, we know rather little about how to shape instruction in order to help them realise the scientific point of view. Hamza and Wickman (2009), in their study of students' laboratory work, pointed out that the conditions required for students to give a scientific account cannot be defined generally, or beforehand. Instead, "it is a matter of responding to the needs that arise in action, as the students are dealing with the particulars and contingencies of the situation" (pp. 146-147). Kelly and Crawford (1997) described high school students' discourse and actions during physics experimentation and demonstrated that learning about natural phenomena is more complex than can be discovered by an analysis of the students' preliminary conceptions. In their own words: "Rather, constantly shifting socio-cultural contexts are created moment-to-moment through group members' actions and interactions [where the] learning contexts are the product of both outside (e.g., scientists, curriculum planners, policymakers) and classroom-based (e.g., teachers, students, texts, technologies) influences" (Kelly & Crawford, 1997, p. 557). The complex nature of learners' meaning-making of natural phenomena has been demonstrated by Wickman and Östman (2002a, 2002b) in their studies of students' laboratory work with morphological traits in insects. In these studies, it was shown how the students used all sorts of experiences in their meaning-making and how their encounters with the physical objects widened their talk about different aspects of natural phenomena. Irrespective of our interest in the study of how students come to terms with a scientific view of a natural phenomenon, it will also be an empirical matter of "what students themselves define as *their* interests in giving an account of a certain natural phenomenon" (Hamza & Wickman, 2009, p. 1046). Also, in the report from The International Society for Technology in Education (ISTE), Kozma (2003) suggests that relationships found in large-scale studies should be complemented with "more extensive qualitative classroom studies that examine these relationships in a more fine-grained way so as to establish casual mechanisms" (p. 237).

The importance of detailed analysis of how learners collaboratively construct shared meanings in interaction has been articulated by Roschelle (1992), who argues that such a study "cannot prove or disprove a theory, but it can clarify the meaning and import of a set of ideas", and that it moreover "can attract attention to problems that have been overlooked, and create awareness of powerful theories that have not been fully tapped" (p. 268). Results of studies based on qualitative data obtained from detailed analyses can elucidate many of the components forming learners' interactional accomplishments of interpreting instructional technologies. Meaning is not made of language exclusively, but is always used as a part of a complex cultural activity accompanied by gestural, postural, proxemic,[11] situational and paralinguistic information (Lemke, 1998). "Nonverbal signs which co-occur with spoken language, especially 'body language' signs form, with speech, a single integrated meaning-making and interpersonal communication system" (Lemke, 1998, p. 1177). Thus, when analysing human interaction, it is important for the analysts to have access to the participants' gestural and pointing movements. Such nonverbal signs can be essential for the understanding of indexical referents made in speech. Lemke (2001) emphasises that in a socio-cultural discourse analysis, analysts are concerned with functions of language and the ways in which shared understanding is developed in a social context. Here the meaning of any discourse always depends on how it can be con-

11 The term *proxemic* was introduced by the anthropologist Edward T. Hall to describe measurable distances between people as they interact.

nected to some events. For example, what students say in a particular situation gives meaning in relation to the history of his/her experiences. This dependence on the context for interpretation of an ongo-ing activity makes it necessary for the educational researcher to obtain as much information as possible regarding former teaching activities, group dynamics, the subjects' interest in the topic, their cultural background etc. (Lemke, 1998). Furthermore, Lemke (1998) emphasises that the context-sensitivity of any meaning-making activity in education strongly suggests that the learning process has to be studied *in situ*.

Another rationale for applying analysis of interaction in educational research is, as detailed in Chapter 2, the inconsistent learning outcomes brought about by the use of animatied instructional technologies. Comparative studies have been unable to confirm any general measurable learning benefit attributable to the use of any special instructional technology (Russell, 1999). Bereiter (2002) claims this to be caused by the fact that "most treatment variables in educational studies are found to make little or no difference, whereas individual difference variables account for a large part of the variance in outcomes" (p. 326). As an example, Bereiter (2002) makes the supposition that a certain type of educational technology may be better for high-achieving students, whereas another type is better for low-achieving students, which results in the fact that, averaged out over all students, there will be no discernible difference in effect between the two types. Schnotz and Rasch (2005) found that manipulable pictures had an enabling learning function for students with high learning prerequisites, whereas animations had a facilitating function for individuals with low learning prerequisites. Berliner (2002) posits that: "In education, broad theories and ecological generalizations often fail because they cannot incorporate the enormous number or determine the power of the contexts within which human beings find themselves" (p. 19). To deal with the complexities involved in educational research and to collect reliable evidence for arguments about educational issues, Berliner (2002) proposes that such research should focus on methods where local knowledge is produced e.g. ethnographic methods, case studies and design experiments.

A fundamental questions is then how to accomplish research on multimedia use in which people make different meanings from complex media artefacts. From a socio-cultural perspective of learning, Crook (1994) argues that:

> If we do wish to conduct evaluations of what is learned in computer-based contexts, we must go beyond the input-output designs that characterise much research in the area. It may not be enough only to expose a pupil to some software and, some time later, do an outcome test of understanding. The reason this is inadequate is because any such computer experience is more or less situated in some broader framework of teaching activity. In short there is a risk of casting this educational technology in terms that suggest a medical model of how it works. (p. 9)

Social systems seem to have such complex interdependencies that no single input reliably governs any particular output and every effort to control some outcome runs the risk of producing unanticipated and often uncontrollable side effects (Lemke, 2006). We should therefore leave the prevalent approach in educational research, which takes its point of departure from an implicit input-output model where the direct cause and effect relations merely signal what causes what (Lemke, 2006). Instead, Lemke (2006) suggests a "tracer" model where we follow in detail the actual processes through which outcomes are achieved. We should thus aim for an understanding of how any particular social system mediates cause and effect chains that run through them. Having done this for many different systems, we will learn to be sensitive to the kinds of mediations, interactions and differences that are most likely to matter to our interests (Lemke, 2006). More in-depth studies of students' activities is also advocated by Goldman, Pea, Barron and Derry (2007), who maintain that quantitative studies do not explain "the meaning that people ascribe to the events they experience in learning environments" but instead that "ethnographic accounts tell rich stories that help us to understand the meaning of events" (p. 25).

However, objections can be made that studies based on qualitative data do not generate generalisable results. Regarding the generalisability of such studies, Stahl et al. (2006) argue that the results are not merely anecdotal but instead that:

> They can be based on rigorous scientific procedures with intersubjective validity even though they are interpretive in nature and are not quantitative. They can also represent generally applicable results, in that the methods that people use to interact are widely shared (at least within appropriately defined communities or cultures). (p. 416)

Accordingly, studies based on qualitative data can produce general insights into how instructional technologies are used and construed by students in school settings. Empirical studies of students' interaction might also provide information about how to design such instructional technologies to reach the learning goals.

When the researcher is left with a large corpus of qualitative data, one is confronted with the question of how to analyse the data. One way is to quantify the empirical material by making up categories in order to classify the observations for frequency distributions (e.g., Hakkarainen, 2003; Kumpulainen & Mutanen, 1999). As to the advantage of a categorising method of interactional data, Stahl (2002) points out that:

> Of course, the methodology of coding statements is useful for answering certain kinds of questions – many of which are undeniably important. And the methodology can make claims to scientific objectivity: wherever subjective human interpretations are made they are verified with inter-rater reliability, and wherever claims are made they are defended with statistical measures of reliability. (p. 8)

Inevitably, however, the coding of statements results in a reduction of rich interactional material. Stahl (2006) argues that "the reduction of a rich discussion in a database of students notes into counts of how many note fragments ('ideas') fall into each of several categories represents a loss of much information" (p. 219). Stahl also emphasises that "collaborative knowledge building is a complex and subtle process that cannot adequately be reduced to a simple graph or coding scheme, however much those tools may help to paint specific parts of the picture" (p. 221). Since the students' meaning-making process by the coding becomes frozen and dissected "the coding procedures place severe restrictions on the attempts to capture the situated dynamics of peer group interaction" (Lindwall, 2008, p. 40). In reporting results from video research, Derry et al. (2010) comment that "although the ability to code behaviors can rest on the well-developed techniques […] quantification does not allow the researcher to communicate how an interaction unfolds across time in all of its complexity" (p. 23). Thus, dividing the material into preconceived categories inevitably results in risking that the real nature of students' meaning-making process becomes obfuscated.

For the purpose of capturing the details of the students' interaction with each other and the interface, an analytic approach that draws on a tradition that Jordan and Henderson (1995) summarise under the label interaction analysis has been employed in the studies. Through detailed analysis of videotaped material, this analytical framework endeavours to describe the ways participants coordinate both communicative and material resources when performing a given task (Ivarsson, 2004). Interaction analysis has also been employed in the studies as it corresponds with the socio-cultural view in its assumption that learning and knowledge is situated in interaction between participants in specific practices. I find this interdisciplinary method particularly helpful for empirical investigation of technology-mediated learning environments where interaction occurs at different levels simultaneously.

COLLABORATIVE LEARNING

Research concerning computers and learning has initially focused on the relationship between the representational technology and the individual learner. From a socio-cultural perspective, however, it has been stressed by Crook (1994) that the "meaningful relationship" afforded by the technology might be "what is held in common with others and creative collaborations may be especially enhanced by this possibility" (p. 228). Crook (1994) also argues that for schools the computer technology offers a considerable promise in the respect that it "can furnish flexible representations that may become the objects of joint reference for learners" (p. 228). Studies have also shown that collaboration can improve the quality of the learning process and its learning outcomes (e.g., Coleman, 1995; van der Linden, Erkens, Schmidt, & Renshaw, 2000). Hence, learning in small groups in computer-mediated environments has received a growing interest from educational researchers (e.g., Klein & Doran, 1999; Mulder & Swaak, 2002; Rebetez, et al., 2010; Springer, Stanne, & Donovan, 1999; Stahl, 2006).

Especially in the area of computer-supported collaborative learning (CSCL), interaction analyses of knowledge building in small groups has developed into an important methodology. Stahl (2006) maintains that group learning has an advantage over individual learning because the meaning-making process builds on the participants' different interpretations and the interlocutors' accomplishment of an evolving meaning. Computer-supported collaborative learning does not just take the form of online communication, but is equally concerned with face-to-face (F2F) collaboration (Stahl, et al., 2006). To capture the shared knowledge building going on during F2F collaborative interaction, meaning-making can be analysed as taking place across sequences of utterances from the participants: "In this case, the collaboration focuses on the construction and exploration of the simulation or representation" (Stahl, et al., 2006, p. 410). Collaborative learning differs from individual learning in the creating and maintaining of a shared response, but also in the aspect of verbalisation (Rebetez, et al., 2010). In their comparison of collaborative learning settings and individual learning, Rebetez et al. (2010) could not find proof for an improved learning effect of verbalisation per se. However, they did find support for the argument that students working in dyads benefited from grounding a mutual understanding and maintaining a shared representation of their task.

When students work on a problem collaboratively, they need to argue and externalise their ideas so that their partner is able to understand their arguments. In order to benefit fully from collaborative learning, it is important that the students engage in task-focused and reflective interaction (Baker & Lund, 1997). The students then need to reach a consensus about the learning task as well as about basic concepts in the domain. In the schools where the studies were performed, the method of having students work collaboratively with the assignment of giving a report of an instructed concept was frequent in science education. This enabled implementation of the educational interventions as collaborative learning activities. Thus, the student groups were given assignments where they were requested to produce a jointly written response to questions pertaining to their construal of the demonstrated scientific concept. Apart from assumed learning gains originating from such collaborative work, this educational setting also allowed for the researcher to get access to the participants' interactional activities in relation to the instructional technologies.

ASSIGNMENT FORMULATION

The formulation of assignments is of great importance for how the learning technologies is understood and what kind of knowledge the students will acquire in their joint activity of completing the assignment (Bergqvist, 1990; Greiffenhagen & Watson, 2007; Lantz-Andersson, 2009; Lund & Rasmussen, 2008; Nishizaka, 2000). The relationship between the assignment and students' knowledge building therefore has to be considered when researching digital technologies used for educational purposes. This relationship has thus constituted an important aspect in the analyses of the students' work with the instructional technologies.

Lund and Rasmussen (2008) conclude that "the use of computers cannot be understood only by focusing on features in the technologies or the cognitive processes that are activated when using such resources" (p. 388). What "emerges from numerous CSCL studies is a complex interplay between agents, artifacts, and the socio-historical context that weaves resources into a dynamic system of what could be called cultural tools" (Lund & Rasmussen, 2008, p. 388). Lund and Rasmussen (2008) go on to say that when studying technical devices for educational purposes, we have to be aware of the "complex relations that exist between agents, tasks, and tools in CSCL environments" and we "need to align task design with the development of technological features" (p. 410). Referring to findings derived from three studies of secondary school students' joint engagement in solving mathematical problems presented via educational software, Lantz-Andersson (2009) concludes that:

> The students are, hence, familiar with the fact that school tasks are usually developed in certain ways. When they do not come to agreement about how to understand the task, the strategy of looking at the task from the non-present designers' perspective becomes an important resource for them in their continuing understanding of what the

> task entails, for their continuing problem solving and, thus, for their development of knowledge. (p. 101)

In school activities, the teacher is usually the one formulating the assignment and is also the one evaluating the students' accounts. The teachers' involvement in the construction of the assignment and the assessment of their students' produced accounts has therefore been an essential part in the design of the instructional technologies. So, for example, in Study II, the students' assignment was reformulated after discussions with teachers in response to the results from Study I. Also, in Study III, where three learning interventions were enacted, the assignment was reformulated in both the successive interventions after discussions among researchers and teachers.

STUDENTS' CONSTRUCTION OF AN ACCOUNT

The creation of a written report of a concept that is dynamically represented requires of the learners both their interpretation of the representation and the production of a linguistic account of the events (Tomlin, 1997). For students as newcomers to an area, this in itself imposes difficulties of different levels. Not only should occurrences be properly experienced and understood, there is also the added complexity of somehow transforming this experience into linguistic, and eventually, written form. Another complication for the students when describing a represented scientific phenomenon is that the school system requires them to express themselves in a school discourse at the same time as they are supposed to use their own words, and not simply copy written information (e.g., Lund & Rasmussen, 2008).

A transformation of an experience into a linguistic expression is necessarily structured by the grammar of our language (Halliday, 2004). Halliday (2004) stipulates that "understanding and knowledge are semiotic processes" (p. 11). Hence, our meaning-making and understanding of events are affected by grammatical rules of the language. In a written description of an event, the students face the problem of grammatically constructing sentences of what is happening. "The sentence in its basic structure consists of a verb and one or more noun phrases" (Fillmore, 1968, p. 21). This problem of lexical selection of verbs and nouns for insertion in a sentence depends grammatically on so-called *frame features*, into which a given verb may be inserted (Fillmore, 1968). An event is typically described with the entities holding *subject* and *object* roles (Tomlin, 1997). In a dynamic event, some component is *attentionally detected*, which grammatically "maps just that parameter into syntactic subject" (Tomlin, 1997, p. 172). For example, large size or animacy may result in particular attentional detection and thus give such things an active subject role in the observer's linguistic description of an event (Tomlin, 1997, p. 182). Tomlin therefore recommends that when we study how visual representations of events are mapped into language, we should start by looking at the *attentional focus* of the observers.

The scientific language differs in some respects from everyday language, which is an important aspect to consider when assessing students' verbal accounts of a represented concept. Lemke (1990) observes that scientific language is a special genre and constitutes a particular way of talking about the world. Special features of scientific language are its grammatical preference for "using passive voice" and its use of "abstract nouns derived from verbs instead of the verbs themselves" (Lemke, 1990, p. 130). Scientists would, for example, say that something was "dissolved in water" instead of that "water dissolved" the same thing. They would also talk about "the representation" of something, instead of "how they represent" something. Lemke goes on to say that these scientific ways of describing natural events in *passive form* and to use *nouns* instead of verbs is not what learners are used to, which may result in that students find science hard to understand, and thus refrain from the subject matter.

As the review above has demonstrated, students' written accounts of instructional technologies are influenced by diverse factors. Students' joint account is, thus, a result of particulars and contingencies of practice emerging in their interactional accomplishment. A written account, produced either as a shorter description of what is learnt from some kind of exercise or as a more comprehensive report of a knowledge area, is normally assessed by the teacher. As alluded to earlier, a teacher, qua specialist, draws on different experiences than students do in judging such a written account. Furthermore, a teacher or another evaluator of students' accounts normally does not have access to the students' interactional work. I consider empirical studies of students' collaborative reasoning, particularly suitable to make explicit the intricacies involved in their interpretation of the instructed concept. Empirical analyses of students' interactions might constitute a valuable contribution to our understanding of how actions and grammatical processes are involved in the production of such accounts.

STUDY SETUP

For the purpose of obtaining video data for studying the students' exploration of the instructional technologies, the learners were required to collaborate on a given task at the same computer during the filmed sessions. This was also the way in which the instructional technologies were intended to be employed in the educational interventions. Thus, the enactment of instructional intervention coincided with the requirement for doing research. The students' interaction with the interface, and with each other, is assumed to constitute a base for their scientific reasoning about the described phenomena. This organisation, with the students working collaboratively with the same assignment, facing a computer screen, also offers the possibility of making the interaction between the individuals, and between the students and the interface, visible for analytical purposes.

The question then arises about the appropriate number of students working together in the activity. When working collaboratively in front of a computer screen, the physical arrangement of the interlocutors and the monitor poses limitations on students' access to the interface at the same time as they participate in discussing the observed phenomenon (Roth, 2001). Gestures and gazes constitute a central role for communicating in connection with representations, as they are important in order to identify deictic referents to the representational media (e.g., Goodwin, 2000; Lemke, 2006; Mondada 2006). Roth (2001) found that although a group size exceeding two individuals does not exclude participation in the conversation, it curtails their mutual orientation and their active engagement in the interaction by preventing them from gesturing (p. 45). Roth (2001) therefore suggests the arrangement of two students working in front of a computer screen as it helps a speaker make aspects relevant to her/his explanation salient. But Roth (2001) also remarks that if the physical arrangements allow, three or even more learners can work together at the computer.

Accordingly, in order to study the students' socially constructed meanings but not impede any participant's opportunity to partake in the communication, the preferred group size in the educational interventions was limited to two students, although in a few cases there were three students in a group due to practical reasons. Students were thus grouped in pairs in the order in which they were posted on the class list. Groups that were to be video recorded were selected in the way that if there, for instance, were four groups to be filmed in a class of 20 students, the first and then every third group on the list were asked if they would approve of being filmed. If one or both of the students in a selected group declined to be filmed, the next group on the list was asked. Almost all students approved of being filmed.

The demand of doing design-based research "on educational tools and materials in real settings" (The Design-Based Research Collective, 2003, p. 8) implies that an intervention should be conducted in actual classroom activities. In accordance with this request and my earlier claim of the importance of conducting educational research in a classroom context, the research interventions in the studies were all planned with the intention of being conducted in real school settings. One can, of course, question what constitutes a real classroom setting. Simply the circumstance of having research conducted in a classroom is not what would be termed as an ordinary school situation. Furthermore, the video filmed groups were separated from the other groups during their work. The separation of the filmed groups was made in order to allow for the video recordings to be analysed without disturbing noise from surrounding groups. In spite of these somewhat exceptional situations, I have chosen to regard the studies as having been conducted in a real classroom setting, mainly for two reasons. Firstly, the instructional technologies were well integrated into the curriculum and they were introduced by their teachers in their ordinary classrooms. Secondly, it was not an unusual situation for groups to be separated during computer work because computers were unevenly allocated in the school facilities. Hence, even though the filmed groups were placed in separate rooms during their work in front of the computer, they were still part of the whole educational setup, they were provided with the same assignment and their upshot was assessed on the same grounds as other groups.

VIDEO RECORDINGS AS DATA SOURCE

For the purpose of educational research, video analysis has proven to be a useful tool (e.g., Derry et al., 2010; Erickson, 2006). Video recording bears with it the possibility of exposing different kinds of communicating resources and to "examine past activities not as *past* but rather as 'formerly present'" (Laurier & Philo, 2006, p. 188). Linguistic expressions in the form of spoken language or text can be made visible retrospectively to the researcher through tape recordings or written documents, but video is unique in its ability to make available, in retrospect, what occurred in an interaction.

In a study of two completely dissimilar activities, such as girls playing hopscotch and archaeologists at work, Goodwin (2000) demonstrated, from videotaped material, how construction and interpretation of human actions are accomplished through talk, bodily displays and material structures within a situated interaction. According to Goodwin (2000), material structures in the surround "can provide semiotic structure without which the constitution of particular kinds of action being invoked through talk, would be impossible" (p. 1489). Different kinds of semiotic resources are, thus, made publicly visible through the human body as a site for a range of structurally different kinds of displays.

The increased use of video coincides with an interest in the role of tools and artefacts in a socio-cultural perspective of learning (e.g., Säljö, 1998), and also with a more praxeological perspective[12] in educational research (e.g., Mondada 2006). These perspectives motivate an in-depth study of how learning is interactively accomplished through mediating artefacts in an on-going activity. In their seminal work on video technology for interaction analysis, Jordan and Henderson (1995) state that:

12 The praxeological perspective here refers to the location of cognition not in the head of a lone subject but in the production and recognisability of actions as they are designed and dealt with by the participants (e.g., Schegloff, 1991).

> Video technology has been vital in establishing Interaction Analysis, which depends on the technology of audiovisual recording for its primary records and on playback capability for their analysis. Only electronic recording produces the kind of data corpus that allows the close interrogation required for Interaction Analysis. In particular, it provides the crucial ability to replay a sequence of interaction repeatedly for multiple viewers – and on multiple occasions. (p. 39)

An apparent advantage with adopting video in research on learning is the opportunity to reveal the multimodal resources humans use in interaction, such as linguistic features, gestures, gazes, body movements and object manipulations. Lemke (2006) emphasises that all human semiotic resources, such as speech and various body-gestures, form an integrated system of communication for meaning-making, which implies that all communication is multimodal and thus has to be studied as such. Lemke (2006) furthermore asserts that to understand multimedia use we need research on how people use this kind of media in various ways because people differ in how they interpret semiotic signs. For example, Roth (2001) identified patterns that simultaneously occurred at multiple levels by analysing video data from a physics classroom where students learned to explain computer-animated micro-worlds. Video analyses of learning activities have brought into focus representational artefacts, social configurations, physical arrangements and students' interaction. As pointed out by Goldman et al. (2007):

> Video has played a significant role in the learning sciences by demonstrating what constructivists have long contended – that our theories emerge through our deep engagement with what we see by attending closely to the process of learning rather than by only attending to the results of a given treatment or a group of people in an experimental lab-like situation. (p. 26)

Thus, video constitutes a powerful tool for generating data for analyses of students' understanding of an educational intervention, and thereby provides means of unravelling what is going on in a learning activity. By video analysis, it should be possible to find out how students perceive various aspects when interfering with a represented phenomenon and to bring into focus students' descriptions of simulated events.

Video-analytical methods are also called for as a consequence of an emergent interest in design-based experiments that can be of direct use for educational practice. Analysing learning and interaction in retrospect offers educational research a unique opportunity to provide answers not only about *what works* and *what does not work*, but also about *how it works* and *why it works*. Analyses of video recordings where students interact with each other and the interface gives valuable information about how educational software is used and construed. This quality of video analysis is an important aspect when the research is concerned with design and development of educational aids. As remarked by Bereiter (2002), "When the observer is interested in design, much can be learned about how to improve a design by observing it in operation" (p. 324). Koschmann, Stahl and Zemel (2007) argue that this is particularly true in design-based research where it is important to acquire detailed information about how and why an educational intervention works. Koschmann et al. (2007) also remark that the tasks of design and analysis must be treated as distinct activities, which does not mean that design and analysis is independent of each other. Instead, design must be informed by analysis, but analysis also depends on design in its orientation to the analytic object.

Ethical considerations constitute a particularly delicate issue in research that generates video-recorded data as the subjects' identities are disclosed in the film. This means that studies using video data have to put extra weight on obtaining informed consent from the subjects (Derry, et al., 2010; Hall, 2000; Jordan & Henderson, 1995). Studies conducted in schools often require elaborate informed consent procedures with signatures from both students and, in the case of minors participating, even parents (Derry, et al., 2010). In the studies reported here, informed consent was obtained from teachers as well as students for the video recordings. In Study III, even parents' signatures for their consent were obtained for those students who were to be video filmed, as it was required by the school administration. Individuals appearing on images for publications were anonymised as in Study III. When this was not applicable, as in Study II, additional permits were obtained from the students concerned.

SELECTION OF DATA

Observations from design-based research interventions generate a vast amount of data (Brown, 1992). The studies reported here produced a diverse set of data, such as field notes, students' written accounts, interview answers and video recordings. As the research focus was on the students' collaborative reasoning, the video recordings constituted the primary data material, which was also used for deeper analysis. This does not, however, mean that the other data were superfluous; instead they were used as important background data to identify analytically interesting phenomena that could be studied in the video recordings. Thus, the larger data corpus consisting of field notes, students' written accounts and interview answers were first examined for aspects of interest for further analysis. The analysis of the video recordings then started with making a content log for an overview of the data. After repeated viewing of the video data corpus, segments representing particular sequences of interest were located and chosen as *intermediate representations*.

> Such intermediate representations can help researchers strategically select events for deeper analyses that adequately cover major themes and include key participants and hence constitute a kind of representative sample from the macroevent. The conversations and nonverbal behaviors from such a sample, which are often transcribed, become the selection for deeper analysis. (Derry, et al., 2010, p. 9)

A selective process like this will naturally mean that the researcher's preconceptions will be imposed on the analysis. "Selective emphasis is a fundamental and unavoidable process that strongly shapes video research at every step during all phases of inquiry"(Derry, et al., 2010, p. 14). In this initial selective process, it is to the largest possible extent important to keep "free from predetermined analytic categories" (Jordan & Henderson, 1995, p. 43). Such categories are instead expected to emerge from the "deepening understanding of the orderliness of the interaction as participants on the tape make this orderliness visible to each other" (Jordan & Henderson, 1995, p. 43).

However, the analyst take on the data cannot be neglected, and a way to redeem this bias is to show the selected segments in an interdisciplinary work group of researchers. “Collaborative viewing is particularly powerful to neutralize preconceived notions on the part of researchers and discourages the tendency to see in the interaction what one is conditioned to see or even wants to see” (Jordan & Henderson, 1995, p. 44). Accordingly, the selected sequences were then transcribed before they were demonstrated and commented on in a group of researchers concerned with analysing interaction and learning. Left with analytically interesting video sections, “it is incumbent on the researcher to assess which observations are of general patterns [which] is done by finding other instances of the event in question in the data corpus and checking whether the proposed generalization holds” (Jordan & Henderson, 1995, p. 46).

Thus, after the viewing and commenting in a larger group of researchers, sequences of interest were selected for further analysis and for presentation in the papers included in this thesis. This selective process had the criterion to choose sections that represented major themes identified in the lager data corpus, but also instances that could be found to be analytically interesting in relation to the research questions for the project. These motives for the selection usually coincided. However, there were instances when the analytical interest of an episode was not just motivated by its representativeness. For example, in Study III the particular dyad analysed was chosen not only since their dialogue contained a wide range of issues concerning the concept that was also debated in the other groups, but also because of the fact that after maintaining different views, these students came to an agreement on the intended description of the concept.

Analysis based on video recordings naturally brings up the issue of the generalisability of results derived from this kind of data. Regarding the representativeness of instances taken from a larger data corpus, Erickson (2006) points out that:

> The analyst’s task is not only to show what is happening in key instances, but to explain to the reader how and why those instances are of key importance analytically, that is, where those instances presented and discussed in detail fit into the overall patterns of variation that are found within an event as a whole, or across a number of examples of such events. (p. 185)

Derry et al. (2010) argue that criticisms about the generalisability of findings from video data "can be countered by paying explicit attention to the logic of one's inquiry, including one's approach to selecting or collecting records, and by articulating the processes used to create explanations and generate claims" (p. 15). Also, to get a more grounded view when reflecting on what theoretically motivated questions might be pursued, it can be "fruitful to combine video records with other forms of data, including data from performance assessments, interviews, and surveys" (Derry, et al., 2010, p. 16).

Accordingly, to get a comprehensive understanding of how the instructional technologies were used in practice, the whole research project is grounded in empirical data including field notes and interviews with students and teachers. It is in this context I make the claim that my studies might find their generalisability and their usability for practice.

ANALYSING VIDEO DATA

Video analysis makes use of various analytical methods. As remarked by Derry et al. (2010):

> The learning science is an interdisciplinary field, and video is a tool that enhances various methodologies associated with different, and some would argue incommensurate, philosophical orientations. These include ethnography, ethnomethodology, experimentation, discourse analysis, interaction analysis, and others. But regardless of a researcher's methodological orientation or specific research goals, video offers a means of close documentation and observation and presents unprecedented analytical, collaborative, and archival possibilities, as well as new problems. (p. 5)

The studies presented in this thesis draw on methodologies, such as ethnomethodology (EM) and conversation analysis (CA). EM is centrally concerned with the practical reasoning and the procedures through which participants make social action intelligible (Garfinkel, 1967). CA is an analytic approach used to study verbal conversation. By paying close attention to the details of interaction, CA aims to recover methodical practices, such as *taking turns*, *repair and correction*, and *preference organisation* (e.g., Sacks, Schegloff, & Jefferson, 1974). Thus, for the study of learners' interaction with each other and the interface, I consider both of these analytical approaches to produce detailed information. There are, however, considerations to be made when applying these analytical approaches on video data as not directly aimed at video recorded materials, which is obtained in a technology mediated setting.

In an attempt to extend CA to cases of face-to-face collaborative work in front of a computer screen, Greiffenhagen and Watson (2007) raise questions of how to study instances of visual communication. Analysing video recordings of human computer interaction, they studied how the interlocutors applied the phenomenon of *self-correction* and *repair*[13]. The authors argue that despite the occasional usefulness of CA as a heuristic device to highlight aspects of interaction, they could see problems of applying it directly to instances of visual conduct. For example, in ordinary conversation, repair is tied to the achievement of shared understanding since one co-participant has to gain understanding of the other. However, Greiffenhagen and Watson (2007) found that in instances of teamwork in human-computer interaction, it is not so much that the students have problems understanding each other, but more about what they interactively are trying to achieve. Considering the question of applying a model of CA to the analysis of human computer interaction, Greiffenhagen and Watson (2007) argue that their work "suggest[s] that rather the wholesale transposition of a model of conversation, we should be thinking of bringing to bear the 'analytic mentality' of this approach" (p. 29). The authors furthermore propose that two elements from CA could prove especially helpful in analysing human computer interaction: emphasising participants as analysts, where the features of collaborative work at the computer are oriented to by the participants; and emphasising students' culturally based sense-making practices not as an individual phenomenon but as a socially organised one. Thus, the analyses in the studies are based on what meaning the participants make of each other's actions and utterances.

13 The concepts of *self-correction* and *repair* in conversation are described by Schegloff, Jefferson, and Sacks (1977).

Ethnomethodology brings into focus the issue of intersubjectivity, i.e. the understanding that the individual members of a collaborating group have of each other, and of their joint task. “Assumptions, tacit common sense, and unnoticed background knowledge are the very topics for ethnomethodology, which thus has a lot to contribute to constructing an understanding of just how students learn because or in spite of formal instruction in schools” (Roth, 1995, p. 26). I thus consider EM to be essential in my analytical perspective of social and situated action. As argued by Macbeth (2011):

> We can [...] speak of situated action and what is orderly about it as competent practice, wherein meaning – and thus order – is achieved by disciplined ways of speaking, listening and acting. Those practices – situated practices – are roughly what the phrase “ethnomethodology” points to and recommends for study. (p. 76)

Koschmann et al. (2007) argue that because of EM’s central concern with members’ methods for practical reasoning and meaning-making practice, it presents a useful foundation for video analytic research into the practices of learning. The authors recommend the method of applied EM for doing video analytic work, especially in the area of design-based research. Taking their stance in Garfinkel’s (1967) policy statements for EM research, Koschmann et al. (2007) describe its implications for video analytical work. In line with these policy statements, a single case will do for the purpose of demonstrating some phenomenon of interest. They also state that the video analyst’s job is to demonstrate, in her/his empirical data, what the participants count as relevant and how sense-making is produced *in situ*. Furthermore, Koschmann et al. (2007) propose that the analyst has to document what the participants are doing, rather than what they should be doing based on prior expectations. The analyst’s job is also to render an account of how members provide for their joint understanding through their talk and indexical actions (Koschmann, et al., 2007). With this job of demonstrating phenomena of interest comes also the task of re-presenting the analysed data for an audience.

RE-PRESENTING VIDEO DATA

The hyphen used in this heading stresses the *re-* because it brings out the act of repetition of what was shown in the original video data. Re-presenting video data for an audience in printed form involves significant problems for the analyst. Since audio-visual data often presents a variety of conducts and incidents displayed by the participants, it leaves the analyst with the problem of transcribing the multimodal actions so that they can be reconstructed by the reader as they appeared in the first place. For the purpose of capturing the chronological characteristics in conversation, Gail Jefferson developed a transcript system, furnished with notations, that enables the reader to follow and inspect the analysed talk.[14] Traditionally, this transcript convention, developed within a CA tradition, has been used to represent video sequences for the reader. However, the problem with this type of transcript is that it only captures selected aspects of the interaction, and does not primarily focus on visual conducts, such as gestures or manipulation of devices.

For presenting transcripts of video data, Jordan and Henderson (1995) proposed the use of either parallel horizontal transcripts, consisting of multiple horizontal lines that represent talk and nonverbal activities, or parallel columnar transcripts, represented by analytic streams in side-by-side columns that include both verbal and nonverbal actions. Their discussion of issues concerning video transcriptions and representations is concluded with the following words:

> In summary, transcriptions practice at the present time is in flux. We predict that, given the lack of convincing arguments for the benefits of any one particular standard, practitioners will continue to make pragmatic decisions about which transcription convention is best for their particular purposes. (p. 87)

This lack of a convention for representing video data in printed form still remains. In spite of the many attempts made, the video research field is still in the beginning stages of figuring out compelling representations

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14 The Jeffersonian transcription conventions are outlined in Atkinson and Heritage (1984).

of the complexities in visual phenomena (Derry, et al., 2010; Goodwin, 2001). As predicted by Jordan and Henderson (1995), a variety of modes have emerged to extend transcripts to systems for demonstrating visual conducts.

Some examples of alternative modes for presenting video data in papers are: combinations of written transcripts with arrows directed at sketches of non-verbal actions (e.g., Goodwin, 2000); transcripts accompanied with matching screen shots (e.g., Nishizaka 2000; Mondada 2003); and transcribed data fragments, presented on time lines illustrating the order and extension of events combined with screen shots (e.g., Greiffenhagen & Watson, 2007; Mondada 2006). These examples of different modes of representing analytically important episodes demonstrate, on the one hand, the authors' efforts and dedication to exhibit detailed visual aspects of their empirical data and, on the other hand, the difficulties of conveying multimodal actions to an audience in printed form. The driving force behind the inventions of new modes for representing video data is primarily an urge to provide the reader with the possibility of reconstructing the depicted events as they appeared on the video sequence. Different analytical viewpoints require diverse types of representations, and the analyst always has to choose the representational form that she/he thinks best characterises the analysed data.

In the studies presented in this thesis, I have tried out different strategies for re-presenting the video data. The different strategies reflect the somewhat different focuses of analysis taken in the studies. Study I and Study III make use of traditional written forms of transcripts, yet they differ in their level of detail. Study I is equipped with a rather direct written transcript, as the aim of this study was to explore pedagogical consequences of animations in education. In Study III, a more elaborate Jeffersonian transcript is employed to allow for the presentation of a more detailed analysis of the nature of students' reasoning. In Study II, where I wanted to demonstrate the students' actual gestures and pointing movements towards the features appearing on the screen as referents to what they say, I make use of a transcript style that visually demonstrates complex events in a video sequence of interest. This mode, which is currently under development, is termed *sequential art* (Eisner, 1985; McCloud, 1994), commonly known as comic strips.

In sequential art, it is the possibility of illustrating the sequentiality in what the participants do and say, often simultaneously that makes it an interesting representational style. This mode of representation allows for the analyst to present actions in a comprehensible form to the reader and has effectively been used to demonstrate students' interaction when working with the computer screen as an interface (e.g., Ivarsson, 2010; Lindwall & Ivarsson, 2011). I believe sequential art to be a promising candidate for complementing the variety of already existing representational styles for video data, mainly for two reasons. Firstly, it is conventional and thus easily accessed, especially for readers who are not familiar with CA transcripts. Secondly, with screen shots from the analysed video fragments, one is able to exhibit visual conducts that are not so easily conveyed in written form. Sequential art, as all modes for the representation of audiovisual data, inevitably lacks some of the information from the original videotape. When the excerpts are presented in frames with speech bubbles as in sequential art, there is a loss of some of the information available in a CA transcript, such as intonation, pausing, overlapping speech etc – a disadvantage that can be amended with the appending of a CA transcript.

CHAPTER 5

SUMMARY OF THE STUDIES

The three empircal studies are reported in the form of a book chapter and two articles. These are appended in their original versions in the second part of this thesis. Here I will give a summary of the studies.

STUDY I

ANIMATIONS IN SCIENCE EDUCATION

In this first study, the theme is to explore pedagogical consequences of an animated application that displays the gas exchange in the carbon cycle. The specific field of investigation concerns science education where students' reasoning and interaction when working with the animated sequences is examined. From a total of 40 students attending a science course in a Swedish secondary school, three groups were videotaped during their work with the instructional technologies. A short instruction was given to the students about how to navigate on the web-site, but otherwise there was no tutorial introduction of the topic. The students were given the assignment to write down what they saw happening in the different sequences when they had worked with the animations for 20 minutes. During this time, while having access to the learning application and having the possibility to consult their teacher, the groups were supposed to discuss and jointly give written accounts about what was happening in the animated processes. Through detailed interaction analysis of the video data, it is demonstrated how the students in the three video-recorded groups understood their assignment and reasoned about the animated events. The analysis points to three problematic outcomes of the students' assignment of describing the events displaying the gas exchange. The first two of these outcomes are related to the features of the technology and can be characterised as *misguided attention* and *isolated reasoning*, respectively. The third observation is referred to as *conflicting perspectives* and is related to the students' varying ideas of what resources they are expected to make use of when performing the given assignment.

Misguided attention was manifested in the students' focusing on misleading aspects of the animation. Students' tend to focus on prominent features of an animation, to incorporate everyday language in their description and to impose simple everyday cause-effect relations on the depicted processes (Lowe, 1999, 2003). Examples of misleading features of the studied animation were observable in some of the students' everyday expressions, such as molecules "getting stuck" and "blowing away". These specific wordings were subsequently adopted by other members of the group and by their teacher. The findings moreover demonstrate how easily such inferred notions are accepted and taken up by other students and, in this case, also by the teacher.

Isolated reasoning about the simulated phenomena were observed in situations where students were drawing unintended conclusions, such as that the exchange of gases exclusively takes place in the lungs, or that oxygen is the burning substance in a log fire. Animated sequences as well as other representations show only limited and superficial parts of complex biochemical processes occurring on a microscopic level, and this simplified feature of the representation sometimes gave rise to an isolated reasoning about the phenomena. Coming to these inadvertent conclusions can be quite a plausible consequence if the students only watch the animations and do not read the caption explaining the processes. Reading of the text was not expressed in their assignment and students tended to follow precisely the instructions, which in this case were to discuss with a peer what they could observe and thereafter write down their conclusions. The observed inadvertent interpretations could possibly have been avoided if the assignment had been expressed in a way that had encouraged them to read the educational text. Nonetheless, this isolated reasoning draws attention to the fact that the animations' highlighting of specific events can invite a way of reasoning that is isolated in relation to the overall topic.

Conflicting perspectives among the students about what kind of resources they were allowed to use when completing the assignment apparently resulted from the formulation of the students' assignment, which was expressed in the following way: "Explain in your own words what you can see happening in the different animations". The analysis of the students' understanding of this seemingly straightforward instruction showed that it caused conflicting discussions in two of the three groups. Their quandary concerned whether they just had to explain what they could "see happening" in the animation, as explicitly expressed in the instruction, and thereby disregard what is said in the explanatory text and what they possibly already know about the processes, or whether they should use all available resources to explain what was happening in the animated sequences. Even though the intention with the assignment was to make the students draw their own conclusions from the animated sequences, the formulation of their assignment in fact created an increased uncertainty of how to proceed. Considering these outcomes, it seems important to pay careful attention to the formulation of the assignment students receive in their work with instructional technologies.

As suggested by the results, animations, perhaps more so than static images, can create the illusion that a complete process is being illustrated. The simplified nature of animations offers no way of discerning the chemical process actually taking place, which in some instances can become a pedagogical problem. In this way, the learning environment invites ways of reasoning that, at times, become isolated in relation to the overall topic. The animations are intended to focus on specific relations in the biochemical processes, and they thereby necessarily downplay, or hide, other potentially relevant aspects. As the animations are designed to emphasise molecular relations, this form of highlighting runs the risk of concealing other important molecular reactions. The simplifications of the real course of events will, however, be a consequence of any graphical illustration of molecular processes (Han & Roth, 2006). The fact that something very specific is highlighted by the animation could also indicate that one has a harder time breaking out of that offered frame (Ivarsson, 2003). Regardless of how sophisticated the animation becomes, there will always be grounds for misinterpretations. The observations in the study prove that animations of scientific phenomena provide an educational challenge with a pedagogical potential and point out an interesting field of research. What is suggested by the study, however, is that one cannot take any positive learning outcome from animations for granted and, in some instances, they risk leading to unintended interpretations instead of supporting the intended knowledge construction.

STUDY II

ANIMATION AND GRAMMAR IN SCIENCE EDUCATION

LEARNERS' CONSTRUAL OF ANIMATED EDUCATIONAL SOFTWARE

This second article reports an expansion of Study I. The analytical point of departure is the meaning-making processes taking place when students collaborate on construing the animated processes of the carbon cycle. Study I revealed some problematic outcomes of the students' interpretation of the animated processes. In an effort to alleviate some of these problems, the students in this subsequent study were given a lesson introducing the subject to provide them with more profound background knowledge of the field. To avoid the conflicting perspectives among the students – observed in the first study – of what kind of resources they were expected to use, the assignment was reformulated in a more direct way. In this study, students aged 16-18 years in four classes, totalling 65 individuals, worked in dyads or triads with the assignment of describing what was happening in the animated processes. Seven of the groups were video-recorded during the entire session when performing their work with the animated software. By means of interaction analysis, the video-recorded data was examined to gain an understanding of how the students made use of the computer application for the construction of their jointly written report.

A general feature observed is the students' efforts to create a joint meaning and explain in their own words what is shown in the animated sequences. Typical problems for the students in their construal of the animations are the cause of and driving force behind the observed molecular movements. This can also be described as a problem of assigning specific items in the animated display to *subject* or *object* roles. As an example of this general problem of finding out causality in the animated events, two students' reasoning about the mouldering process is pursued in the analysis. The students' written report of what was happening in the animated sequence of the mouldering process did not meet the standards of current canonical science and consequently was not approved by their teacher. By a close inspection of the students' interpretational work, the analysis aspires to disclose how their conclusions were negotiated and completed.

The analysis specifically inspects how learners make use of available semiotic resources in their effort to construct a written account of what is happening in the animated processes. It is demonstrated how the students struggle to find logic in the mouldering process, matching their interpretations with the educational text and creating their own written description. They first comment on the oxygen molecules that they can see moving towards the decaying log. The oxygen molecules, from then on, constitute the active subject in the students' narration of what is happening in the mouldering process. The motion of the animated oxygen molecules makes them perceptually salient and hence attracts the students' attention. Thus, the information drawn by the students from the animation is driven by this dynamic effect. In the students' construal of the animation, they turn to the educational text in an attempt to find an explanation of what is happening. Although it was not mentioned in their assignment to use their own words when describing what is happening in the events, they strived to use expressions that are more in accordance with their own way of articulating than the vocabulary used in the educational text.

The students' construal of the events is taking place in their interactional effort to grammatically construct a story from two different semiotic resources, i.e. animations and written language. In the students' description of the mouldering process, the oxygen molecules take the role of agents instead of the micro-organisms as described in the educational text. This shift of agency and subject role can be attributed both to grammatical rules that allow inanimate objects to be given an agentive status and to the character of the animation that makes the oxygen molecules *attentionally detected* (Tomlin, 1997). In describing an event linguistically, learners face the problem of grammatically constructing sentences of what is happening. "The sentence in its basic structure consists of a verb and one or more noun phrases" (Fillmore, 1968, p. 21). The problem of lexical selection of verbs and nouns for insertion in a sentence depends grammatically on so-called *frame features* into which a given verb may be inserted (Fillmore, 1968). When framing their sentences, the students derive noun phrases from attentionally detected objects and from the educational text. In the students' effort to express themselves in their own words, they use verbs that differ from the educational text. Grammatical rules allow the verb to be changed within the sentence frame (Fillmore, 1968). However, in the process of changing the verb, the students also alter the agency of the subject. These courses of actions together contribute to give the students' report on what happens in the mouldering process a non-scientific explanation. Thus, the students construct a grammatically correct but not scientifically acceptable description of the event. Lacking definite access to the relevant subject matter knowledge, they consequently cannot judge whether they have given an approvable account or not. The students' only way of assessing their written report is to check if it is grammatically consistent, which they do by perusing the text. When they find that it "sounds good", it makes them satisfied with their account.

Results from this study elucidate that students' joint interpretation of an animated scientific phenomenon is no guarantee for the intended learning outcome, even though it was prepared in a preceding lesson and accompanied by an educational text. These findings expose the problem that learners' interpretation of an animated scientific phenomenon does not automatically result in that the constructed concept is in accordance with the intended concept. Learners, lacking sufficient background knowledge of the subject matter and being without adequate guidance, risk in their construal of an animated phenomenon to divert from the intended meaning and construct unscientific descriptions.

STUDY III

AGREED DISCOVERIES

STUDENTS' NEGOTIATIONS IN A VIRTUAL LABORATORY EXPERIMENT

This paper presents an analysis of problems faced by a pair of students who work jointly in a virtual laboratory to discover designated concepts related to gas solubility in water. In so doing, it addresses key issues related to the role of virtual laboratories in science teaching as well as it gives insights into the joint construction of scientific concepts between students.

A virtual laboratory work was designed as a discovery learning experiment where students are supposed to discover a predetermined outcome with instructed guidance. A difficulty connected with such open-ended discovery experiments is that students have to discover something that they might be conceptually unprepared for (e.g., Hodson, 1996). An interaction analysis of students' collaborative work of discovering scientific concepts provides an insight into the learning process engendered by the instructional technologies. Studies of students' scientific reasoning when interacting with computer tools have shown how computer tools enable learners to use deictic and iconic gestures to make salient certain features to which they link their utterances (e.g., Ivarsson, 2010; Roth, 2001). Also, when obliged to talk about visualised events, learners are confronted with the challenge of constructing grammatical sentences that in some sense match what is happening. This study is based on the assumption that students' scientific reasoning is observable in the form of their interactional conduct in connection with their work with the virtual laboratory.

The virtual laboratory was evaluated in the spring of 2008 at four upper-secondary schools in the area of Gothenburg, Sweden. In total, the evaluation process involved four schools, eight teachers and eight classes, totalling 180 students 16-19 years old. The pedagogical development project, which had the form of design-based research, included pre- and post-tests, interviews, discussions with focus groups and video recordings of students' collaborative work in the virtual laboratory. As part of performing the laboratory experiment, the students were to add the gases oxygen and carbon dioxide successively into a bottle of water and draw conclusions from the effervescence observed when the bottle was shaken, heated and when salt was added. It was revealed in the evaluation of the students' work in the virtual laboratory that the most salient problem was the concept of solubility of gas in water. Ocular evidence of a changed amount of dissolved gas in water is obtained by observing effervescence – the more bubbles that leave the water the less dissolved gas remains in the water. However, the evaluation showed that many students saw the greater number of bubbles leaving the water as evidence of more dissolved gas, which revealed the students' difficulty of construing the increased amount of gas bubbles as a decreased solubility for gas in water.

In order to investigate the nature of the students' reasoning, the video recordings of 13 student pairs who were discussing the virtual laboratory experiments were transcribed and analysed. Initial analyses showed that what caused much of the dilemma were the concepts of *solubility of gas* and of *dissolved gas* in water in relation to the amount of emerging bubbles. The article presents a detailed analysis of two students who discuss the issue of what an increased amount of bubbles means in relation to the solubility of gas in water. This particular dyad was selected for two reasons. Firstly, their dialogue included a wide range of issues concerning the concept of solubility of gas in water, and secondly, they displayed a possibly productive way of solving the problem. The analysis was guided by two research questions: What type of problems do the students encounter in this kind of learning environment? What types of resources do they use to reach an agreement of their discoveries in the experiments?

The results address learners' general difficulty of discovering something that they are conceptually unprepared for. The analysis reveals the dyads' problem of discovering the solubility of gases in water by means of the resources given within the virtual laboratory. A major finding is that the students' problem is not to understand that an increased amount of gas bubbles indicates a decreased amount of gas in water. Instead, the real issues for them are the meaning of the concept of solubility of a gas in water and what it means to dissolve a gas in water. This is demonstrated by the conflicting perspectives maintained by the students in their discussion on how to use these concepts in relation to the amount of bubbles in the water.

In the students' progressing discussion, they maintained two contradictory perspectives of the concept of gas solubility in water. Whereas one of the students described a positive relation between increased bubbling and increased solubility, the other one described a negative relation. Although the students demonstrated different views, they both agreed that the emerging gas bubbles implied that less oxygen remained in the water. Hence, their conflicting perspectives did not concern the link between the amount of oxygen in water and the efflux of bubbles. Rather, their disagreement was about the meaning of the concept of gas solubility in water, or at least the correct usage of this concept, given the circumstances agreed upon. Being stuck with two different views on the concept and neither one being able to vindicate his perspective, the students attempted to find ways out of their conundrum by applying external resources. However, they dismissed this idea since they assumed that they were not supposed to use that kind of source for information. The reason for the students' reluctance to use external information sources is assumed to be found in certain conventions existing in the school culture that direct how to approach and solve tasks (Lund & Rasmussen, 2008).

The two students could have stayed in their opposing views concerning the definition of gas solubility in water had it not been for their discussion following another experiment in the virtual laboratory. In that experiment, where the students poured salt into the water, they observed the same effect as in the experiment when the water was heated, namely an increased amount of bubbles emerging from the water. By creating a linguistic analogy between what happens when salt dissolves in water and what happens when gas dissolves in water, one of the students was able to offer a way out of their dilemma. Their collaboration, where one of the students assisted his companion to reach insight into the concept of gas solubility in water, proved an example of Vygotsky's (1930/1978) notion of the *zone of proximal development* (ZPD), showing that the individual learners' capacity can be enhanced by collaborative work. As a result, the students reached an agreement on the intended outcome, that more bubbles leaving the water implies that a lesser amount of dissolved gas remains.

Three main factors were found to influence the students' dialogue concerning their construal of the animated events and formulation of their answer to the given assignment: (1) the assignment, which obliged the students to linguistically negotiate the meaning of the concept of solubility – a negotiating process that can be seen as an important part of the students' learning process; (2) the school context with its cultural norms, which provides a frame for what kind of resources can be used in accomplishing their assignment; and (3) the students' pre-knowledge of represented concepts. The study demonstrates some of the analytical work that has to be done by the participants when collaboratively negotiating a shared meaning of a scientific concept in concord with a set of instructional technologies. It is argued that the findings help understand learners' practical problems of construing the instructional technologies and also inform design of such technologies. Based on the analysis, one implication for the future design of similar instructional technologies might be to endow students with resources enabling them to utilise their own previous experiences and make connections to related phenomena.

CHAPTER 6
DISCUSSION

The purpose of this thesis is to explore students' collaborative reasoning about scientific concepts in connection with instructional technologies that provide semiotic resources in the form of explanatory texts and computer-animated representations. Video data were used for interaction analysis, which enabled insights into learners' collaborative scientific reasoning. This analytical approach gave access to students' interactional work of accomplishing a shared meaning, and an insight into their production of a jointly written account of the demonstrated scientific concept. As the results show, the students' reasoning when working with the instructional technologies was influenced by several aspects, such as the characteristics of the animated display, language use, school cultural norms, the formulation of the assignment and the students' pre-knowledge.

In this chapter, I will discuss these results in relation to my initial research questions concerning how students collaboratively reason about scientific concepts while using instructional technologies that include animated representations, how students approach the task of interpreting such instructional technologies and what kind of resources they use in their interactional work. In relation to the findings, I will also discuss consequences for design and educational use of instructional technologies that involve animated displays.

STUDENTS' COLLABORATIVE REASONING

Analysis of the students' reasoning when working with the animated instructional technologies showed that *prominent characteristics of the animated display attract the students' attention and form a base for their collaborative reasoning*. This complication with animated representations, which involves that students detect salient features at the expense of more thematically relevant structures, has also been observed by e.g. Kelly and Jones (2007) and Lowe (2003, 2004).

Furthermore, it was observed how *animated objects were described in correspondence to their resemblance of occurrences in everyday life*. In Study I, for instance, molecules were said to "blow away" and "get stuck", expressions which were subsequently taken up by other students and in one instance even by their teacher. This *mixing of scientific concepts with colloquial language* may occur with static pictures as well (Han & Roth, 2006). It can, however, be argued that the dynamics in animation make the model characteristics more pronounced than in a static representation and hence further accentuate learners' tendency to characterise the represented scientific concepts as recognised everyday features. Accordingly, special characteristics of an animation might have considerable consequences for learners' way of describing what is happening in a simulated representation of an event.

Students' use of non-scientific expressions as referents in their activity of interpreting animated representations, which was frequently registered in the studies, has also been reported by e.g. Krange and Ludvigsen (2008) and Lowe (1999). It has been proposed that non-scientific concepts and spontaneous metaphors constitute important resources in learners' reasoning about scientific phenomena (Hamza & Wickman, 2008; Jakobson & Wickman, 2007). Even specialists such as physics scientists have been reported to use such non-scientific utterances when they interact in building meaning of graphic representations (Ochs, et al., 1996). Hence, the use of non-scientific terms seems to be employed both in novices' and in specialists' interactional work of interpreting graphical representations.

However, the difference between these two groups might be that while the novices lack specific domain knowledge and therefore have difficulties realising what kind of scientific concept the everyday expression is referring to, the specialists have no such problem. Thus, the problem is not primarily the students' use of everyday expressions for models of scientific concepts, but rather that they, being novices, do not master the underlying concepts.

Cultural norms were found to influence how the students approached their assignment, and what kind of resources they thought they were supposed to use when solving the same. In school activities, students are most often supposed to give an account of their understanding of the instructed subject. This was also the case in the studied interventions, as the students were required to produce written reports of what was happening in the animated processes. The requirement of giving a jointly written account of the represented scientific concept proved not to be a straightforward assignment for the students. It can be observed how the students expressed concern over what resources they were supposed to utilise in their fulfilment of the assignment. For example, in Study III it was observed how the students restricted themselves in their use of Internet with the motivation that they were not supposed to use that kind of source. In Study I, the students' problem of deciding what kind of resources they were supposed to use could, to some extent, stem from the formulation of the assignment where they were requested to explain in their "own words" what they could see happening in the animated sequences. This formulation was by some of the students understood literally, and thus was given precedence over a wider understanding of the subject. In Study II and Study III, the students' assignment included no such recommendation to express themselves in their "own words". However, even in these interventions the students were anxious not to re-use expressions from the explanatory text or textbooks in their descriptions. Hence, this way of constructing a written account with their "own words" existed as an underlying norm among students.

These findings demonstrate how *the students re-enact norms existing in a school context, and thus adapt their way of completing the assignment according to these norms*. Thus, school culture involves explicit stipulations of assignments and implicit expectations for expressing oneself in one's own words, at the same time as the students are supposed describe a phenomenon from a scientific point of view (Kelly & Crawford, 1997). As expressed by Lund and Rasmussen, "[T]asks are cultural and social constructions and there are certain cultural conventions of approaching and solving tasks" (2008, p. 409). Regarding the delicate problem of task formulation, Lund and Rasmussen (2008) also emphasise that it implies "a need to further theorise the task-tool relationship in activities involving collective knowledge production and the need to align pedagogical as well as technological designs in order to give support for such efforts" (p. 387). Hence, both in the construction and evaluation of students' assignments, one has to consider such cultural norms, which frame the learning and create conditions for how the instructional technologies are used and understood.

Grammar was shown to play a significant role in the students' activity of forming a joint interpretation of the animated events. As shown, prominent features of the animated display were attentionally detected and concentrated on in the students' reasoning. This might have the effect that students, irrespective of the actual activity in the represented phenomena, assign the *agent role* to such prominent features (Tomlin, 1997). An example of this is found in Study II, where in the students' construal of the mouldering process, attentionally detected oxygen molecules were described as the active agents instead of the invisible micro-organisms. The expository text provided the students with factual information about the process and from this text they retrieved noun phrases. In the students' construction of sentences, which described the animated event, they used these noun phrases together with verbs in so-called *grammatical frame features* (Fillmore, 1968). The students then combined these noun phrases with verbs that they, in their ambition to use their own words and not be accused of cribbing, derived from their own vocabulary. This merging of two semiotic resources – the animated representation and the expository text – resulted in that the produced linguistic account, although grammatically correct, did not meet the criteria set up by the evaluating teachers.

Students' pre-knowledge were found to be an important resource in the students' reasoning about the represented scientific concepts. For example, in Study III it was shown that the students' pre-knowledge of the concept of gas solubility in water played a decisive role in their reasoning about outcomes from the virtual laboratory work. Even if the students had understood the chemical and biological consequences of the experiments, their report of the simulated experiments risked being non-scientific. This might be a consequence of the students' lack of access to the underlying scientific concept, which was demonstrated in the virtual laboratory experiments.

Taken together, these results show that the students' reports of the animated representations were not primarily driven by an understanding of the underlying scientific concept as it might be for scientists (Ochs, et al., 1996). Since the students did not have complete access to the specific knowledge domain (Krange & Ludvigsen, 2008) and did not master the special genre of scientific language (Lemke, 1990), they had to rely on resources they possessed as novices in their interpretation of the represented scientific concepts. When subsequently assessing their own report, they only had their everyday experiences and the understanding of grammar to rely on. The consequence of this risks being that students in their interpretational work of instructional technologies construct concepts that are not in accordance with the represented scientific concepts.

The negotiation of a shared meaning of the scientific concepts was shown to be the main engagement in the students' interactional work. In this respect, the instructional technologies have complied with criteria set out by Jonassen (1999) for design of instructions for constructivistic learning. According to Jonassen (1999), instructional material should give students access to knowledge building tools that encourage conversations about the problems, and thereby engage students in conceptual and strategic thinking. Yet, as the results show, the students did not regularly create the scientific concept of a demonstrated phenomenon. Instead, the students' interpretation of a demonstrated concept often diverted from a canonical scientific one. These findings warn against assuming that collaborative meaning-making, where students' work with instructional technologies, automatically leads to a creation of the desired scientific concept.

IMPLICATIONS FOR PRACTICE

The studies underlying this thesis were all part of design experiments where the outcomes from the analyses were to inform the design of the instructional technologies in further interventions.

The two successive studies (Study I and Study II) were connected in a way that outcomes from the first study informed the educational framing of the subsequent study. For instance, in Study II, the educational intervention was complemented with a lesson prior to their work with the instructional technologies that informed the students about the taught subject. Based on observations from Study I, the assignment was reformulated in Study II in order not to cause the conflicts over what resources they were supposed to utilise. In Study III, the analysis was made on video data from a sub-study of a design experiment in which three different versions of the instructional technologies were implemented. In addition to the video recordings, various kinds of data, such as ethnographical observations, questionnaires and interviews with teachers and students, were collected from each of these three interventions. The evaluation of the instructional technologies was based on these data, and outputs from the first two learning interventions formed the basis for a redesigning of the instructional technologies, which was then re-enacted in subsequent interventions. Thus, in the iterative design processes conducted in the studies, the findings from the analysed video data provided the research team with valuable information about the students' interpretations of the instructed scientific concepts. This information constituted an essential source for the process of re-designing the instructional technologies to reach the learning goal. In this respect, the studies demonstrate the usefulness of video analytic research for supporting design processes (Koschmann, et al., 2007).

The design of animated representations of abstract scientific phenomena, such as molecular processes, poses considerable problems for the designer. A molecular process, as the word *process* signifies, involves some kind of activity. Such a process often takes place at several levels simultaneously, and thus renders it virtually impossible to visualise as it occurs in nature. An animated display must also show biochemical reactions that are taking place over a substantial length of time (days, weeks or even years) in just a few seconds. An example of this is the mouldering process discussed by the students in Study II. To clarify such a gradual and, in some parts, passive process in an animated display, the designer sometimes has to simplify and exaggerate the motion of certain objects in the display. As has been demonstrated in the studies, such a dynamic effect risks giving objects an *agency* and *activity* (Tomlin, 1997). Consequently, animated representations run the risk of leading a novice to an unscientific construal of the event.

Suggested means to cope with such problems of unintended interpretations of animated representations for educational purposes include, for example, increased interactivity (Tversky, et al., 2002), activities that generate explanations and supplying the learning application with study questions (Mayer, et al., 2005). Within a multimedia presentation, one also has the possibility to employ additional modalities, such as a voice that explains the events. Regarding learning outcomes from animated representations complemented with narration, Mayer and Moreno (2002) argue that "students learn more deeply from animation and narration than from animation and on-screen text" (p. 96). However, with a narration accompanying the animated display comes, in classroom settings, the requirement of headphones, which in turn implies restrictions on the communication possibilities between students involved in the joint interpretation of the representation.

When re-designing the animated instructional technologies, several considerations can be made for the advancement of the same. One plausible way might be to furnish the animated representations with illustrations of processes occurring inside, for example, organisms or substances. However, such an expansion of the animated representation with additional details, risks making the representation more complex and hence more demanding for the learners (Mayer, 2001; Mayer & Moreno, 2002). Another way to enhance the instructional technologies might be to elaborate on the exploratory text to make it more informative. Yet, it is questionable if a more extensive text will result in better understanding of the phenomenon; instead it might lead to students refraining from reading the entire text.

Prominent features taking precedence over other less conspicuous but thematically relevant features poses a special problem for designers of animated representations of scientific concepts. Unintended interpretations can, to some extent, be attributed to the simplified character of an animation. The animated sequences may to some degree be modified to rectify such undesired interpretations. It is, however, important not to raise too great expectations in the technology as a sole pedagogical saviour (e.g., Säljö & Linderoth, 2002). Technologies like the ones studied have to be considered as just an aid to teaching, because it is "uncertain whether, in any deep sense, the tasks of a teacher can be 'handed over' to a computer, even the most 'responsive' one that can be theoretically envisioned" (Bruner, 1996, p. 2). When considering re-designing computerised 3D molecular models to overcome problems with students' undesired interpretation, Krange and Ludvigsen (2008) remark that:

> It is nonetheless important to emphasize that students' interpretations of these kinds of representations are never a given. This means that such initiatives always have to be supported by other kinds of interventions, such as those designed for the website or those initiated by the teacher. (p. 46)

Based on the findings described above, I think, for the use of animated representations in education, that it is important to take into consideration the limited capacity of media to convey complex natural phenomena. Animated representations, like any model of a scientific concept, brings with it simplifications as well as exaggerations of certain characters (Han & Roth, 2006). Complex molecular processes, occurring at different levels simultaneously, cannot be realistically portrayed and there seems to be no immediate way of designing an animated display to overcome such drawbacks. Consequently, regardless of how sophisticated animated representations become, there will always be grounds for unintended outcomes that risk producing non-scientific concepts of the illustrated phenomenon. This emphasises the necessity to exploit means of complementing animated instructional technologies in order to meet educational challenges. The need for support from other kinds of interventions as, for example, those initiated by the teacher also shows the importance of communicating the findings to the educational system. Otherwise, the teaching practice will not be aware of possible consequences of the use of animated instructional technologies, and thus will not have the opportunity to benefit from the best use of such teaching aids.

An aspiration of my studies has been to communicate the findings to the school system, including administrators and teachers, with the ambition to inform the practice. To what degree this objective has been met is at the present stage uncertain. Important steps were, however, taken in the research approach to encourage that the results will have implications for teaching practice.

Firstly, the studies, as being part of design experiments, involved both the school management and the active engagement of teachers in the iterative process of the design and enactment of the instructional technologies. The inclusion of teachers in design studies "can help researchers and designers understand the real-world demands placed on designs and on adopters of designs [and the] close collaboration with teachers places them in direct ownership of designs" (The Design-Based Research Collective, 2003, p. 8). For example, in Study III where the project involved researchers and teachers both in Sweden and in California, several of the teachers from Gothenburg were invited to Stanford University to discuss the design of the instructional technologies with their Californian counterparts. The involvement of school management, and not least of engaged teachers, which was a prerequisite for the studies to be undertaken, might vouch for a sustained interest and employment of these kind of instructional technologies.

Secondly, the subjects presented in the instructional technologies were well integrated in the curriculum and were part of the syllabus in the classes where the learning interventions were performed. This might mean that the instructional technologies will be employed as a teaching aid in future lessons of the subject.

Thirdly, the produced instructional technologies are available for free as web-based software. This allows for schools, both those involved in the design-based research projects and others, to use the software at their own discretion.

CONCLUSIONS

I argue that the findings show the usefulness of video analytic research. Detailed analysis of students' interaction, informed by conversation analysis and ethnomethodology, can aid in the process of uncovering impediments to learning and the possible identification of pathways around such obstacles. This analytical framework can support design processes and provide useful information about how to reach learning goals. The socio-cultural approach adopted in this thesis has directed the analytical focus on learning and knowledge building as a situated and social process that is mediated by tools.

The interaction analyses of students' collaborative reasoning made it possible to identify aspects important for students' interpretations of the instructed scientific concepts. Students' collaborative reasoning about the animated processes showed to be a result of several aspects, such as formulation of the assignment, animacy in the representation, language use, students' pre-knowledge and school cultural norms (Fig. 2). The characteristics of these different aspects, and the way in which they interplay in the students' collaborative reasoning, were shown to in some instances lead the students to produce interpretations of instructed scientific concepts that differ considerably from the intended.

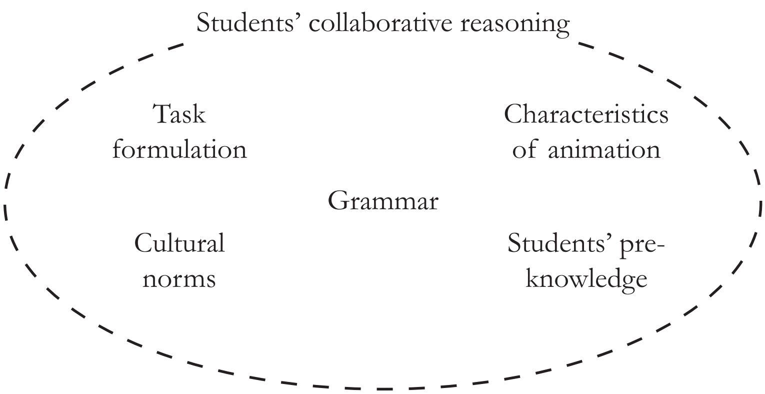

Figure 2. A sketch illustrating the aspects found to be comprised within students' collaborative reasoning when working with the instructional technologies.

The assessor (usually a teacher) of students' reports, as being a specialist in the area, has in contrast to the students the underlying scientific concept as the referent in her/his judgement of the report. However, as the analyses show, the students' joint report of an instructed scientific concept can only be understood in relation to the entirety of the components illustrated in Figure 2. If we can get access to the reasoning processes leading to students' accounts, we can gain a more complete picture of what is involved in their interpretations of instructional technologies. Basing assessments of students' accounts of a represented concept firmer on the reasoning process and less on a static written report leads to a more nuanced understanding of students' interactional work. The analytical framework that I have used in this study has shown that students' reasoning often reveals a more advanced understanding than what is reflected in their written account. These observations pose a challenge both for educational researchers and designers to really go thoroughly into, and try to understand, students' interpretations of instructional technologies as a process. To paraphrase Roth et al.: simply labelling students' interpretations as wrong instead of capitalising on their efforts to describe what they have observed may result in the students feeling ridiculed and refraining from generating interpretations of the depicted phenomenon and in a missed opportunity to build on the students' ideas to create more canonical conceptions (1997, p. 133).

Animated representations, compared to static ones, offer new and exciting possibilities to illustrate scientific concepts in instructional technologies. However, as exemplified in the studies, new modes of representations also entail didactical complications in the students' ways of interpreting what is happening in the events. From an educational point of view, the results reveal several complications with students' interpretations of the instructional technologies. Results presented in this thesis, and elsewhere, clearly demonstrate that there are no straightforward ways in learners' interpretation of animated representations that describe scientific concepts. The results do not support the assumption that an animated representation as such enhances understanding of a scientific concept. Neither have other studies found consistent proof of animations' primacy over traditional learning devices (for a review see Tversky, et al., 2002). On the contrary, it is indicated that animated representations of scientific concepts risk resulting in unintended construals if students are left on their own with the interpretational work. Grounded on these results, one cannot claim the supremacy of animated instructional technologies for learning scientific concepts. One may thus argue that compared to traditional representational methods, animated representations do not possess specific properties that enhance learning of scientific concepts, and could as well be abstained from as instructional technologies. However, I believe that taking such an argument as a motive for refraining from further use and research on animated learning technologies would be like throwing out the baby with the bathwater.

Actually, there is not, and probably never will be, any instructional technologies that offer a panacea for learning abstract scientific concepts. Scientific achievements that have taken centuries of intellectual and research efforts to accomplish will not easily be conceptualised by means of a single educational intervention. Animated instructional technologies in science education have to be considered an aid, but nothing that can guarantee an intended learning outcome. This emphasises that animated instructional technologies cannot be supposed to function as a *stand-alone* educational tool (Kelly & Jones, 2007). Therefore, when applying instructional technologies in education, one has to consider a wider context where assignment formulation, teacher guidance, school culture and semiotic processes influence in what manner students approach and frame their assignment.

Despite the many complications in students' construal of animated instructional technologies, the results point to factors speaking in favour of the use of animated representations. To be capable of proffering an alternative to well-tested teaching aids, animated instructional technologies have to be developed and refined by *sustained innovation* (Bereiter, 2002). Developmental efforts thus have to involve sustained innovation based on research results for students to benefit from animated representations in science education. Such developmental efforts have to include the awareness of students' ways of reasoning and thereby enable refinement of instructional technologies to better meet the educational demands.

Reflecting on my initial reference to Bruner's (1977) prospects for technology in education, my observations have led me to comply with his initial claim about the possibilities of new teaching aids to extend the students' range of experiences and dramatise the significance of what is to be learnt. However, considering my results and other research in the area, I do not concur with Bruner's optimistic view of new technologies easing the teacher's burden. Instead, new teaching aids seem to pose new didactical challenges for educators. To meet these challenges, the teacher has to gain knowledge about what kind if implications new instructional technologies might have for the students' construal of the instructed concept.

Accordingly, the teacher has to take appropriate actions in her/his teaching to ensure that the students are eventually led to an intended learning outcome. Clearly, the results emphasise the importance of guidance and/or a tutor-led debriefing following the students' exploration of the instructional technologies. Here, the teacher should ideally build on the students' reasoning when they work with the instructional technologies and not so much on a final account.

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