Learning to reason in environmental education

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Learning to reason in environmental education

Digital tools, access points to knowledge and science literacy

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Abstract

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Digital technologies and environmental education represent two rather new areas in school curricula. The background of the present research is an interest at the inter-section between how students learn about environmental issues (e.g., climate change) and the role digital technologies may play in such contexts. Thus, the aim is to investigate tool-mediated activities in environmental science education. The digital tools that are used in the instruction in this research are a virtual laboratory and a carbon footprint calculator. The study is guided by the questions of how digital tools co-determine activities and students' reasoning about scientific knowledge and environmental topics, as well as what implications the use of such tools have for the development of science literacy. Analytically, this is studied within a sociocultural perspective on learning and by relating it to Dewey's view of learning through inquiry. The empirical material consists of questionnaires and video data. The thesis consists of four studies. Study 1 builds on the analysis of questionnaire data from a corpus of almost 500 students' written pre- and post-test answers to a problem-solving question in which they are required to design an experiment before and after working with a virtual lab. The second set of data comprises video recordings of upper secondary school students' work with the two virtual tools. The results are presented in Studies 2 and 3. In addition, and in relation to the interest in science literacy more generally, Study 4 focuses on students' work with an assignment requiring them to

evaluate research reported in two scientific article abstracts on climate change. On a general level, the findings show that digital tools incorporate conceptual distinctions and operations that provide "shortcuts" for the students' reasoning by providing access points to complex knowledge about the environment. This means that the students are able to engage in sophisticated discussions about environmental issues linked to human-driven climate change without requiring too much specific prior knowledge. However, the results also point to dilemmas connected to the use of such sophisticated tools. That is, for students to make meaning in ways that are relevant to understanding scientific argumentation, some of the processes and conceptual premises need to be unpacked by a competent partner (e.g., a teacher). Through engaging in such tool-mediated activities, students develop new cognitive habits, that is, new ways of reasoning which are made possible through the support of the tools. Thus, in sum, the present empirical studies demonstrate that digital tools have the potential to reconfigure learning activities that support students' development of science literacy in environmental science education. At the same time, the analyses show that the tools are abstract and far from self-instructive. They index complex forms of knowledge that are not always transparent to the users. Thus, to reach curricular goals, the use of such tools in environmental science instruction presupposes guidance and support by teachers.

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Study 2: Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013). Virtual labs as context for learning—Continuities and contingencies in student activities. In E. Christiansen, L. Kuure, A. Mørch, & B. Lindström (Eds.), *Problem-based learning for the 21st century. New practices and learning environments* (pp. 161–189). Aalborg, Denmark: Aalborg University Press.

Study 3: Edstrand, E. (2015). Making the invisible visible: How students make use of carbon footprint calculator in environmental education. *Learning, Media and Technology, 41*(2), 416–436.

Study 4: Edstrand, E., Lantz-Andersson, A., Säljö, R., & Mäkitalo, Å. (2016). Deciphering the anatomy of scientific argumentation: The emergence of science literacy. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.

APPENDIX

A. Consent form
B. Transcript convention

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Limhamn, December 2016
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1. Introduction: Evolving technologies and environmental education

The research reported in this thesis addresses the inter-section between how students (young adults) learn environmental science, and the role that digital technologies may play in this context. Environmental education, in relative terms, is a rather new area of schooling that clearly presents challenges for educational practices in the sense that the topics addressed are complex and multidisciplinary, relating to nature, to society and human behaviour, and to questions of sustainability.

In recent decades, the use of interactive digital technologies has become a part of most activities occurring in society; such tools have also gained increasing prominence in teaching and learning in schools and in other educational institutions (cf. Erstad & Sefton-Green, 2013; Lantz-Andersson & Säljö, 2014). People are surrounded by digital tools, and these tools play a central and natural role in their lives. Searching for all kinds of information, reading newspapers and magazines, banking, social networking, experiencing virtual reality events, and participating in simulation-based activities are examples of activities that people engage in by using their smartphones, tablets, or computers. The expansion of online activities has also resulted in learning contexts that are open to global communities. In this sense, "[d]igital technology is a topic that is of significance to a global educational audience," as Selwyn (2013, p. vii) put it.

Digital technologies offer possibilities for learning that significantly differ from traditional text-based materials. For instance, they are multimodal and interactive, and they make it possible to integrate images, sound, and animation in dynamic interplay. In this manner, digital tools complement, but sometimes also challenge, the traditional media (e.g., textbooks) used in schools (Säljö, 2010). By opening up new ways of presenting interactive information, digital tools co-determine, that is, they play a decisive role in students' understandings and ways of reasoning, which in turn brings about new conditions for organizing learning and learning experiences. This development has resulted in new arenas of research and raised questions about how to optimally support both educators and students in discovering meaningful ways to utilize digital technologies in different instructional settings (Furberg, 2016; Greiffenhagen, 2012).

One arena of research where such questions have been raised is environmental education, which, in many countries, has become an increasingly important curricular activity in contemporary schooling (Stokes, Edge, & West, 2001). Environmental education became compulsory in primary and lower secondary education in Europe in the 1970s (United Nations Educational, Scientific, and Cultural Organization [UNESCO], 1975). This makes it a relatively new subject in instructional settings, and in recent decades its expansion has been fuelled by a drive to educate young people about the environment and issues of sustainability, emphasized in the Rio Declaration on Environment and Development in 1992, the World Summit on Sustainable Development in Johannesburg in 2002 (Combes, 2005; Gough, 2014; UNESCO, 2004), and in many other international declarations and agreements (e.g., United Nations FCCC, 2015). The purpose of environmental education is to provide young generations with opportunities to learn about the environment in ways that are crucial for citizenship in the 21st century. For instance, the United Nations International Panel on Climate Change (UNIPCC) predicts that "the continued changing climate will have widespread effects on human life and ecosystems" (Anderson, 2012, p. 192). Rising sea levels, droughts, and the like are examples of climate changes which affect people in terms of "human, material, economic and environmental losses" (Anderson, 2012, p. 192). Thus, education has an important role to play in educating students about, for example, the use of resources and the impact human activities have on the climate (cf. Meerah, Halim, & Nadeson, 2010). Such aspects are emphasized by the Swedish national curriculum for the compulsory school, preschool class and the recreation centre:

> Environmental perspectives in education should provide students with insights so that they can not only contribute to preventing harmful environmental effects, but also develop a personal approach to overarching, global environmental issues. Education should illuminate how the functions of society and our ways of living and working can best be adapted to create sustainable development. (Skolverket, 2011, p. 12)

However, as political and economic interests differ between countries (Stevenson, 2007), the implementation of such curricular content is not a straightforward and uniform instructional mission. For teaching and learning practices, such content includes attending to topics that are contested in terms of the use of resources and that depend on national and international political collaboration. Thus, environmental topics are interesting and challenging from a knowledge point of view, since they require insights into many fields and an ability to think at the systems level. That is, the ability to consider causes and consequences of environmental changes at a macro-level and in terms of interdependencies between nature and human activities (Sterman, 1994).

In the literature, many of the areas that are important in environmental science are referred to as *socioscientific issues*, for example, the greenhouse effect/global warming, and genetically modified organisms (Christenson & Chang Rundgren, 2015; Dawson, 2015; Jakobsson, Mäkitalo, & Säljö, 2009). Such issues deal with questions of an interdisciplinary character, where students are expected to learn to analyse problems from different perspectives, for example, from scientific, economic, political, and ethical points of view (Åberg, 2015; Dawson, 2015; Sadler, Barab & Scott, 2007; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005).

A central element of learning about socioscientific issues as a part of schooling is learning to *talk science* (Gyllenpalm, 2010; Lemke, 1990). Talking science implies an understanding of science and scientific knowledge that goes beyond recognizing and defining "scientific concepts and facts" (Gyllenpalm, 2010, p. 18). Learning to talk science involves insights into the logic of scientific investigations, that is, how scientific knowledge is produced, communicated, and validated. These elements of talking science are fundamental constituents in the development of science literacy (Roberts & Bybee, 2014). Thus, students' learning about climate change is interesting from a broad educational perspective, connected to central competences relevant for citizenship in contemporary society. This aligns with the broad research interest of my thesis, which presents findings on students' learning about scientific knowledge relevant to understanding environmental issues.

In contrast to school subjects such as mathematics and language, environmental education does not rest on long teaching traditions when it comes to form and content of the subject. This means that environmental education perhaps may be regarded as a less inert arena in relation to the more traditional school subjects, and this in turn provides means for opportunities to introduce new tools and new ways of working in the classroom. Research has also shown that new digital tools are continually introduced and made available for learners in the context of environmental education (see Fauville, Lantz-Andersson, & Säljö, 2014, which present a literature review on the use of ICT in environmental education).

There are several studies that have investigated technology-supported environmental education in areas such as virtual field trips (Jacobson, Militello, & Baveye, 2009), virtual museums and marine organisms (Tarng, Change, Ou, Chang, & Liou, 2008), and virtual games and the ecosystem endemic to the Mediterranean Sea (Wrzesien & Alcañiz Raya, 2010). One example of recent developments concerns applications referred to as virtual labs. The principles underlying virtual labs, on one level, originate in traditional school labs: By interacting with digital tools through a digital interface, students can engage in laboratory work which, on one level, resembles lab activities of the traditional kinds organized in schools (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014; Gibbons, Evans, Payne, Shah, & Griffin, 2004; Heerman & Fuhrmann, 2000; Zacharia, 2008). On another level, virtual labs are different from traditional school labs both in terms of what experiments are possible to include in classroom settings and the nature of the activities in which students engage. Tools that measure carbon dioxide emissions related to people's actions comprise another example of such relatively recent innovations. There are now several carbon footprint calculators available online, and they are designed to support people in understanding the relations between activities in their personal lifestyles (e.g., concerning transportation, food, consumption, and waste) and carbon dioxide emissions (Fauville, Lantz-Andersson, Mäkitalo, Dupont, & Säljö, 2016; Hopkinson & James, 2010; McNichol, Davis, & O'Brien, 2011). Such calculators also have interesting features that hold promise for understanding and learning about emissions and their consequences. In the research reported in my thesis, students' activities related to these two specific digital tools will be analysed.

The studies in my thesis are underpinned by a sociocultural and what Greeno, Collins, and Resnick (1996) refer to as a situative/pragmatist-sociohistoric perspective on learning. This implies that learning is viewed as a matter of appropriating cultural tools (Säljö, 2011; Vygotsky, 1978; Wertsch, 1998). The unit of analysis for understanding learning therefore includes cultural tools, how they mediate understanding, and the ways in which the students make use of them when interacting with fellow students (Säljö, 2009; Wertsch, 1998). Cultural tools make it possible for people to master abstract functions, such as remembering, calculating, comparing, and analysing, which otherwise would be difficult, or even impossible, to carry out (Vygotsky, 1997, p. 86). Cultural tools are seen as resources that support, and often foster, different modes of reasoning, and in this way they mediate knowledge in new ways. As an instance of the situative/pragmatist-sociohistoric family of perspectives, the study also makes use of Dewey's (1938) concept of *inquiry*. The concept is used to analyse students' activities when engaging in problem solving, which aims at promoting insights and skills that are often construed as constitutive of science literacy.

Thus, the research conducted in my thesis scrutinizes how the virtual lab and the carbon footprint calculator serve as mediating resources in student learning and reasoning about environmental issues that specifically concern ocean acidification and climate change. These cultural tools are brought into the classroom for use in instruction, and they invite new ways of working, discussing, and understanding in the field of environmental education. As a part of the classroom environment, the tools support certain activities and actions, and in this way they establish interactions and relationships between the students, between the students and the tools, and between the students and the teacher. Put differently, the virtual lab and the carbon footprint calculator co-determine the pedagogical practice; they form integrated parts of the meaning-making practices. These two tools are a part of studied learning activities with a general research interest that concerns the ways in which students learn about scientific reasoning and scientific methods of inquiry in topics related to environmental education. The point of departure for the work is that the value of a digital resource for learning cannot be determined unless it is studied in context. Therefore, rather than examining the potential of digital tools as such, my studies focus on the tool-mediated activities in the context of students' learning and reasoning in environmental education.

Context of the studies

The studies in this research are connected to a research project called Inquiry-to-Insight[1] (I2I). The point of departure for the I2I project has been to develop tools and practices for supporting students' learning about

[1] The I2I project was funded between 2008 and 2013. In 2015 the project resumed under the new name, Inquiry to Students Environmental Actions (I2SEA).
http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r1b/i2s.php#

environmental issues and climate change. The I2I project is a collaboration between the University of Gothenburg through the Sven Lovén Centre, the University of Gothenburg Learning and Media Technology Studio (LETStudio), the Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society (LinCS), and Stanford University in the United States. I2I offers an educational programme that combines IT, social networking, and pedagogy to address environmental issues. One of the ideas behind I2I is to connect classes from different countries within a social network so that students can compare views and attitudes about climate change; the purpose of such activities is to increase their understanding of sustainable development. Marine biologists at Stanford University and the University of Gothenburg designed and developed a virtual lab (Acid Ocean Virtual Lab) in which students practise experimentation relevant for understanding environmental issues and use a carbon footprint calculator that measures personal carbon dioxide emissions. My thesis project is a part of the educational section of the I2I project and my empirical materials were generated from students' activities with the tools and tasks designed by scientists of I2I.

The four empirical studies included in the thesis represent instructional activities that take place in everyday schooling practices. The research builds on two types of core data, questionnaires and video recordings, which formed the basis of two articles and two book chapters. In 2010, I2I conducted a pre- and post-intervention survey with about 500 American students before and after they worked with the virtual lab. This extensive questionnaire data set was collected by the I2I team for evaluation purposes, and parts of it make up the foundation of Study 1. The analytical interest in Study 1 relates to the *products* of student learning in the sense that the analysis focuses on students' written answers in terms of how to design an informative experiment in the area of ocean acidification.

Studies 2, 3, and 4 build on video recordings of classroom activities in a Swedish setting that involved upper secondary school students attending a specific programme in marine biology. Thus, the video data collected constitute the main data used in this thesis. The analytical interest in Studies 2, 3, and 4 primarily concerns the *processes* of students' learning activities, that is, how students and teachers engage in activities using a virtual lab (Study 2), a carbon footprint calculator (Study 3), and student assignments consisting of writing reports scrutinizing scientific claims (Study 4). These empirical materials focus on students' interactions, their tool-mediated and collaborative activities, their discussions, and the written documents they produced.

Aim

The overarching aim of the thesis is to explore tool-mediated activities in the context of environmental education. As pointed out, two different digital tools were studied as a part of instructional practices: a virtual lab and a carbon footprint calculator. Based on a sociocultural approach to learning, this research aims to scrutinize how these specific digital tools trigger students to reason about research on the one hand and, on the other, about environmental topics that concern climate change. Thus, the unit of analysis in the thesis is students' reasoning in such tool-mediated activities. The general research questions addressed are as follows:

- In what ways do digital tools co-determine the activities and students' reasoning and learning about scientific knowledge relevant to understanding environmental topics?
- What implications will the use of such tools have for the development of science literacy?

Outline of the thesis

The thesis consists of two parts. The first part provides a background to the field of research of digital technologies and environmental education, theoretical and methodological underpinnings of the study, a summary of the studies, a discussion, and a summary in Swedish. The second part consists of the four empirical studies. Chapter 2, gives a more general introduction to issues of digital technologies. In addition, Chapter 2, includes a review of the research on virtual labs and carbon footprint calculators in instructional settings. Research within this field has been carried out in different domains; therefore, this review includes studies representing different perspectives on the use of these tools. Chapter 3 offers a brief description of environmental education and the instructional challenges in this rather new field of teaching and learning. This overview also covers some of the relevant literature in the area of students' learning about socioscientific issues and science literacy. Chapter 4 presents the theoretical framing and analytical perspective of the thesis. Some of the premises of the sociocultural perspective on learning and Dewey's view of learning through inquiry are discussed. Chapter 5 deals with the research context; the chapter describes the investigated setting and the empirical materials, and presents a discussion of the digital tools—the Acid Ocean Virtual Lab and the carbon footprint calculator. Chapter 6 introduces the research methods and explains how the two types of data included in the thesis (i.e., pre- and post-intervention survey and video recordings) were analysed and how ethical issues were addressed. Chapter 7 presents a summary of the studies. Finally, Chapter 8 provides a concluding discussion of the results. Chapter 9 is an extended summary in Swedish.

Part two consists of the following empirical studies:

1) Petersson,[2] E., Lantz-Andersson, A., & Säljö, R. (2013). Exploring nature through virtual experimentation. Picking up concepts and modes of reasoning in regular classroom practices. *Nordic Journal of Digital Literacy, 3*(8), 139–156.

2) Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013). Virtual labs as context for learning—Continuities and contingencies in student activities. In E. Christiansen, L. Kuure, A. Mørch, & B. Lindström (Eds.), *Problem-based learning for the 21st century. New practices and learning environments* (pp. 161–189). Aalborg, Denmark: Aalborg University Press.

3) Edstrand, E. (2015). Making the invisible visible: How students make use of carbon footprint calculator in environmental education. *Learning, Media and Technology, 41*(2), 416–436.

4) Edstrand, E., Lantz-Andersson, A., Säljö, R., & Mäkitalo, Å. (2016). Deciphering the anatomy of scientific argumentation: The emergence of science literacy. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.

[2] Current name: Edstrand

2. Digital technologies in education: A background

This chapter aims to position the thesis in relation to previous research in the area of learning with digital tools in education generally, but also specifically, in the context of environmental education. The chapter starts with a broad overview of the use of digital technologies in education and the implications for instruction in order to provide a background for analysing the field of environmental education. It continues by focusing on studies investigating the integration of the two tools that are central in my studies, virtual labs and carbon footprint calculators, as used in environmental education. Thus, the chapter provides a foundation for the interest of exploring what the use of such tools implies for students' learning activities.

Digital technologies in education and implications for instruction

Since digital technologies were introduced in schools during the 1960s, their potential for use in educational settings has been of great interest to many. Politicians, researchers, teachers, parents, producers of software and hardware, etc., have been discussing, and still are discussing, digital technologies in terms of their benefits and limitations in the contexts of teaching and learning (e.g., Bulfin, Johnson, Nemorin, & Selwyn, 2016; Cuban, 2001; John & Sutherland, 2005; Selwyn, 2008). As mentioned in the introduction, when compared to traditional text-based materials, digital technologies offer added resources for communication and expression. They are multimodal, which is to say that they offer possibilities that include, for example, the integration of images, sound, and animation in texts in ways that enable richer presentations and representations of information. Users are also frequently able to interact with and to manipulate the interfaces and smart graphics. In addition, through sophisticated resources such as search engines, people have access to information in new ways; information can easily be saved, shared with others, and used in instructional settings. In this manner, students have access to various sources for learning that make new kinds of learning activities possible (cf. Lantz-Andersson & Säljö, 2014).

Although digital technologies involve all the above-mentioned possibilities and many more, the history with respect to their implementation shows that their introduction into instruction has not been straightforward. Even if teachers, to some extent, have included such resources in their teaching, they generally seem to have used them in accordance with established and, in many cases, rather traditional approaches to instruction (Cuban, 2001). The traditional approach is characterized by a teacher-centred instruction, meaning that the "teachers lecture, and students listen, read textbooks, and complete individual exercises presented in workbooks or photocopies" (Cuban, 2001, p. 96). As Greiffenhagen (2012) put it, "when we look at actual cases of the adoption of various technologies, we find that teachers have selected those that fit with their existing practices" (p. 39). This means that the instructional setting is kept rather traditional regardless of whether the students use textbooks or digital technologies, and the possibilities of digital tools are not always exploited (cf. Lantz-Andersson & Säljö, 2014). The perspective taken in my research implies that students' use of digital technologies needs to be studied as activities in their own right, where the digital tools are seen as resources that may offer new kinds of learning experiences but that do not necessarily do so (cf. Kluge, Krange, & Ludvigsen, 2014). Thus, I assume that an empirical question is to what extent inherent features of the tools are used, and this in turn depends on the kinds of instructional activities that are organized as these resources are introduced.

Seen from this perspective, digital technologies not only add to the teachers' repertoire of tools for use in instruction, but they also interact with the instructional possibilities. Thus, the ways in which teachers present digital tools and how they organize teaching in such environments will have implications for what is possible for students to learn (Greiffenhagen, 2008). Consistent with this idea, researchers have shown that teachers' support in activities with digital technologies is more crucial for students' learning than ever before (e. g., Furberg, 2016; Greiffenhagen, 2012; Jornet & Roth, 2015; Strømme & Furberg, 2015). For instance, Strømme and Furberg (2015) argued that

> [t]he teacher's intervention constitutes the "glue" in the setting by providing support in the intersection of peer collaboration, digital resources, and instructional design; when something goes awry in the intersection of these

> various forms of support, the teacher becomes the last layer of support. (p. 859)

Strømme and Furberg drew attention to the fact that teachers have a critical role in a computer-supported, collaborative learning setting in science by using "glue" as a metaphor for the teacher support that connects the various components of what is to be learnt, which will also often serve as a "last layer of support."

The teacher's role is addressed in one of the four studies in my thesis (Study 2). However, and as is further discussed in Chapter 8, the findings from Studies 2 and 3 also show windows of instructional opportunities, that is, sequences in the interaction in which the involvement of a teacher would have supported the students' learning and guided their use of digital tools.

Impact studies

The majority of studies within the field of digital technology in instructional settings could be described as impact studies with a systemic approach (Arnseth & Ludvigsen, 2006; Rasmussen & Ludvigsen, 2010). This implies that they search for the kinds of impact or effect digital technologies have on students' learning. Furthermore, the aim of such studies is to investigate students' learning outcomes when they use various kinds of digital tools (e.g., Clark & Sampson, 2007; Seethaler & Linn, 2004; van Joolingen, de Jong, & Dimitrakopoulou, 2007). According to Arnseth and Ludvigsen (2006), in studies applying a systemic approach, "the nature of teaching and learning is pre-defined at the outset and, by the same token, how participants themselves actively establish contexts for learning is simply disregarded as analytically uninteresting" (p. 174). In this sense, impact studies differ from research applying a dialogic approach to learning[3] and communication (Arnseth & Ludvigsen, 2006), where the empirical interest instead concerns how learning is constituted in social practices by the parties involved. In line with this, by applying a sociocultural perspective (Säljö, 2000; Vygotsky, 1978; Wertsch,

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[3] It is worth noting that the results from Study 1, including the participants' written answers to a pre- and post-test, did not focus on evaluating whether the students learn more or less when engaged in activities using a virtual lab. Rather, the scope of the analysis was to explore potential signs of learning by identifying how they picked up concepts and reasoned about possible ways to organize experiments to study the effects on marine organisms if a fish hatchery was built. In addition, the analyses of the students' answers resulted in a category system (see Chapter 7, p. 81) that was empirically derived, meaning that the answers formed the basis for describing the categories.

1998), this thesis employs an analytic focus on activities and discussions that evolve in tool-mediated settings. This focus implies that my thesis seeks to answer questions about, for example, how and why students navigate in certain ways in the virtual lab and how students, when working with tools such as virtual labs and carbon footprint calculators, appropriate domain-specific knowledge. In the next section, I elaborate on some of the features of virtual labs. This is followed by a discussion on findings from studies utilizing systemic and dialogical approaches to students' learning through virtual experiments.

Virtual labs

There is now extensive research on the benefits of using virtual tools in a range of instructional practices. Virtual labs exemplify one such virtual tool (de Jong, Linn, & Zacharia, 2013; Olympiou & Zacharia, 2011). In the present research, virtual labs represent interactive environments that often are designed with an interface that mimics a physical school laboratory. Furthermore, such environments offer possibilities for the user to manipulate symbolic information on a screen (cf. Kocijancic & O'Sullivan, 2004; Tatli & Ayas, 2013). For example, through drag and drop interactions with laboratory equipment (e.g., microscopes and beakers), users are able to practise various kinds of experimentation and see the outcomes of their activities.

From an instructional point of view, virtual labs have many interesting qualities: They are interactive, and they make it possible to perform experiments that can extend over long periods of time, that is, the duration time of an experiment can be manipulated so that an experiment that lasts for two weeks in a physical context will take only one hour to perform in a virtual lab (Zacharia, 2008). In addition, virtual labs enable students to practise experiments that may be dangerous or which, for other reasons, such as costs, are difficult or impossible to carry out in school (Bhargava, Antonakakis, Cunningham, & Zehnder, 2006; Bose, 2013; Darrah et al., 2014; Shim, Park, H.-S. Kim, J. H. Kim, Park, & Ryn, 2003; van Joolingen et al., 2007). Students can also work with virtual labs independently and at their own pace (Bose, 2013), and since experiments may be paused, students can continue them in the next class. All these factors make virtual labs an interesting alternative for teaching and learning. Furthermore, the interactivity and increasing flexibility of virtual tools in terms of richer and more dynamic scenarios allow for more varied forms of interaction while experimenting (de Jong, Martin, Zamarron, Esquembre, Swaak, & van Joolingen, 1999; Kollöffel & de Jong, 2013).

To sum up, virtual labs imply new opportunities for organizing instruction and for learning, including the learning of scientifically relevant modes of working. Through experimenting with different kinds of well-designed scenarios, students can acquire knowledge about the nature of scientific research as such. However, for virtual labs to function in an educationally relevant manner, additional issues have to be considered. For instance, most virtual labs convey an oversimplified view of scientific inquiry, which may hinder, rather than promote, the development of understanding scientifically relevant ways of conducting research. Therefore, it is vital for students to learn that "authentic scientific inquiry or problem solving seldom takes place in perfect conditions" (Chen, 2010, p. 1127), and they have to realize that the virtual environment often presents too clean a picture of what lab work involves.

In the following section, I will present a review of literature on virtual labs and the use of such tools in instruction. The overview will summarize studies representing different perspectives on the use of virtual labs.

Learning through virtual experiments

A number of studies investigating virtual labs as contexts for learning have been reported in areas such as physics, chemistry, and biology. These kinds of studies provide details related to the development and to specific features of the design of virtual labs, and they repeatedly report on and discuss the effects these virtual environments have on learning. For instance, Ramasundaram, Grunwald, Mangeot, Comerford, and Bliss (2005) developed an environmental virtual field laboratory (EVFL) that is related to the environmental properties of flatwood landscapes[4] in Florida. The EVFL is a virtual environment in which the students have the possibility of investigating environmental processes related to the flatwood landscapes. The students select various scenarios (e.g., silvicultural treatments) and learn about the ways in which a specific configuration of factors impact ecosystem processes. The purpose of the EVFL is to offer a complement to regular field trips. The idea is to mimic a traditional field trip by using animation, 3D models, questions,

[4] Flatwood landscapes in Florida were described by Lu, Sun, McNulty, and Comerford (2009) as "a mixture of cypress swamps and pine forests, and cover about 5% of Florida's forest land" (p. 826).

and simulations. The authors argued that EVFL enhances learning, as it offers better instructional opportunities compared to non-virtual labs (see also Fauville et al., 2014, a literature review on the use of ICT in environmental education). Similar arguments were highlighted by Heermann and Fuhrmann (2000), who developed a virtual laboratory within a physics modelling environment. The authors stressed the importance of developing an "educational system that allows not only the transfer of video, audio and documented material (for example, via whiteboards), but also the interactive simulation or playing with new material" (p. 11). Furthermore, Heermann and Fuhrmann claimed that the students can, by themselves, work with the virtual lab, which means that they have the opportunity to investigate scenarios and situations that might not have been focused upon by the teacher. According to the authors, circumstances like these increase students' motivation to learn.

The focus of the above-mentioned studies is on the development of virtual labs. The studies, however, do not investigate activities evolving in classroom settings when students are using virtual labs. As argued by Fauville et al. (2014), "there seems to be a much greater interest in designing such tools than in analysing how their use contributes to shaping student learning and understanding" (p. 273). Considering that these tools are intended to be implemented in instruction, it is a serious shortcoming not to study them in actual use, since, as I discuss later, technologies do not determine human action. Next, I follow up on this by presenting research that has investigated students' work with virtual labs. As already alluded to, these studies can be categorized into two diverse approaches, systemic and dialogic, each of which addresses different analytical interests.

Research about how virtual lab work interacts with student learning often has a comparative design in which the students' use of such tools in lab work activities is compared to what emerges in traditional hands-on labs (Olympiou & Zacharia, 2011; Sun, Lin, & Yu, 2008; Tatli & Ayas, 2013). In a study that utilized a systemic approach, Darrah and colleagues (2014) sought to illustrate that a virtual physics lab could produce the same learning outcomes as traditional hands-on lab experiences. The authors developed the Virtual Physics Lab, a virtual lab environment in which students practise various kinds of experiments about, for example, Newton's second law of motion. The tool contains virtual experiments and resources for supporting students when analysing, reporting, and evaluating results from the experiments. For example, the students position a ruler on data recording paper in order to measure the position of spark marks. After having measured the positions of the spark marks, they document the results in a data table. The study was conducted with the participation of 224 students from two large universities. In order to test the effects of the use of the virtual lab, the participants were divided into three groups, where they a) conducted traditional hands-on labs (control group), b) conducted virtual labs instead of traditional hands-on labs, and c) conducted virtual labs supplementary to traditional hands-on labs. A post-test consisting of questions on the objectives of the labs, along with the students' lab reports, were used to assess the learning. In addition, the authors analysed students' answers to questions from three semester exams, which were associated with the content in the virtual labs. The analyses of the data showed "no evidence that one of the treatments (virtual or hands-on) was more effective than the other in conveying the concepts of the labs to the students" (p. 812). Furthermore, Darrah and colleagues argued that the students transferred the physics concepts included in the virtual labs and the traditional hands-on labs in similar ways. The study concluded that the Virtual Physics Lab can be just as effective as traditional hands-on labs. Consequently, the authors state that the virtual lab environment can be used as an alternative or as a supplement to hands-on labs in physics courses. In particular, the authors pointed to the benefits of using virtual labs in instruction, as they are both time- and cost-efficient.

Another study on the effects of virtual labs on student learning was reported by Gibbons and colleagues (2004). This study, which, in line with the one by Darrah et al. (2014), applied a systemic approach, included first-year undergraduates in the Department of Biological Sciences at Brunel University; the object of their research was an understanding of chromosome analysis. Gibbons and colleagues (2004) formulated the hypothesis that in certain situations, virtual labs can enhance learning in a way that is comparable to that which takes place in a traditional lab. In the study, 47 students were divided into two groups; the first group (A) received traditional instruction consisting of a lecture and an exercise. The exercise comprised practical work in which the students were given a photo of chromosomes, scissors, and glue as tools for analysing chromosomes. The other group (B) worked with a virtual lab in which they received the same lecture as Group A. In the virtual lab, the students worked on drag and drop interactions related to chromosome analysis. The findings of this study showed that all students preferred to work with the virtual lab compared to the traditional lecture. The teacher was also positive about using the virtual lab in the practical work of analysing chromosomes, particularly as it offered opportunities for the students to work with exercises at their own pace. The authors argued that the virtual lab is much less time-consuming than traditional teaching and that the decrease in time did not negatively influence the students' achievements.

Studies employing a systemic approach, as the ones described above, tend to focus on virtual labs as a way of speeding up time for learning; I would argue that by approaching the issues in this way, they simplify what it means to learn science and to learn about rather complex conceptual relationships. Rather than investigating effects or pursuing comparative issues, the empirical interest of the present research is to focus on the virtual laboratory activity as such. That is, my interests concern the interactional processes that unfold in activities when students interact and use tools, and not only consider the built-in opportunities that the tool offers through its design (cf. Arnseth & Ludvigsen, 2006; Cuban, 1986, 2001).

Other studies adhering to a dialogic approach have similarly focused on students' understanding in ongoing work with virtual labs (e.g., Furberg, 2009; 2016; Karlsson, 2012; Karlsson, Ivarsson, & Lindström, 2013; Strømme & Furberg, 2015). For instance, Furberg (2009) explored secondary school students' activities related to their work with the Norwegian virtual tool "Viten.no," which is a Web-based inquiry learning environment that, through texts, links to websites, tasks, animation, and multiple-choice tests, aims to support students' reflections on genetics and on ethical aspects of gene modification. The Web-based environment also includes prompts that asked students to write answers to questions in a workbook. The questions asked in this research concerned "[w]hat opportunities for action are embedded within the Web-based learning environment 'Viten.no', and how do these opportunities for action become structuring resources for the students' participation in scientific inquiry?" (p. 2). The analysis was based on video recordings of students (15–16 years old) from two secondary schools as they worked for one week in pairs with Viten.no and prepared for a classroom debate on the ethical perspectives of the genetic modification of food. During the following week, they worked in groups of four to prepare for a classroom debate. The results showed that the students' answers to the prompts were short and non-argumentative and that they used a copy-and-paste strategy when writing answers in their workbooks. However, by studying the process in addition to the students' answers to the prompts, Furberg (2009) demonstrated that students, in non-prompting activities in the Web-based inquiry environment actually did engage in reflections related to scientific knowledge, for instance in discussions about protein synthesis. In such activities, students reflected on their understanding of protein synthesis, discussed related concepts, and formulated explanatory accounts. If the goal is to understand the instructional implications of using such resources, it is significant to study the activity of students' work in Web-based inquiry environments and not only the effects or outcomes.

> Findings from a variety of studies have improved our understanding of the *effects* of different types of prompts. However, when it comes to understanding the opportunities generated by Web-based inquiry environments, as well as how these opportunities for action become structuring resources for students' participation in scientific inquiry, detailed analyses of students' interaction while engaging with Web-based learning environments are required. (Furberg, 2009, p. 11)

Furberg suggested that by exploring the nature of the activities that unfold when using virtual labs in instruction, analyses can reveal insights into how students make meaning when engaging in such activities and what resources they use. The present research follows this knowledge interest. Analyses of video recordings of students engaging in virtual lab work contribute to an understanding of the kinds of activities that evolve when they are involved in virtual experimentation.

Virtual labs exemplify one type of generative digital tool that provides interesting opportunities for instruction in the context of environmental education. Another example of a tool that is relevant in such instruction is the carbon footprint calculator.

Carbon footprint calculators

The studies presented in this section concern the uses of a carbon footprint calculator and/or an ecological footprint analysis[5] designed to measure

[5] Carbon footprint calculators and ecological footprint analyses are both tools for measuring peoples' footprints; however, they differ in how they measure such footprints. A carbon footprint calculator measures personal carbon dioxide emissions in kilograms or tons, whereas an ecological footprint analysis is used as a method of measuring the land area necessary "to produce the goods and services consumed by residents of that country, as well as the capacity needed to assimilate the waste they generate" (Kitzes, Peller, Goldfinger, & Wackernagel, 2007, p. 1; see also Wackernagel & Rees, 1996).

peoples' impact on the environment as resources for learning. The concept of a carbon footprint started to appear in the media around the year 2000 (Wright, Kemp, & Williams, 2011); now, however, the concept "has become a commonly recognized phrase, frequently used to describe the concept of relating a certain amount of GHG [greenhouse gas] emissions to a certain activity, product or population" (Wright et al., 2011, p. 61). Both carbon footprint calculators and ecological footprint analyses are tools that use specific methods for scrutinizing and visualizing the environmental impact of human habits, and they build on designs assuming that people answer questions where they provide estimates about various features of their lifestyles.

Today, there are large numbers of calculators available online. Through the use of such tools, people can calculate their carbon footprint values by entering information about personal habits regarding transportation, home energy use, food habits etc. Organizations such as The Nature Conservancy,[6] the United States Environmental Protection Agency (EPA),[7] WWF,[8] and the Center for Sustainable Economy[9] present carbon footprint calculators on their Web pages with the explicit idea of encouraging people to calculate their carbon footprints in order to increase their insights into the impact their lifestyles have on the environment.

Several studies have examined and compared the designs of different carbon footprint calculators. Most of these studies (Murray & Dey, 2008; Padget, Steinemann, Clarke, & Vandenbergh, 2008) concluded that there is little consistency between the calculators. Fauville and colleagues (2016) argued that one aspect related to the inaccuracy of such tools concerns the questions asked about the user's lifestyle. From a design point of view, these questions are complex since "the designers have to make simplifications and generalizations that reduce the accuracy (but increase the user friendliness) of the tools" (Fauville et al., 2016, p. 182). Also, and as is further elaborated on in Chapter 8, there is no general and agreed-upon definition of how to measure carbon dioxide emissions when calculating carbon footprints (Birnik, 2013; D. Pandey, Argawal, & J. S. Pandey, 2011; Wright et al., 2011). This means that people who use, for instance, the carbon footprint calculator on

6 www.nature.org/greenliving/carboncalculator/index.htm
7 www.epa.gov/climatechange/ghgemissions/ind-calculator.html
8 footprint.wwf.org.uk
9 www.myfootprint.org

the WWF's website might get a result that is different from that of those who use the calculator on The Nature Conservancy's website. Furthermore, a carbon footprint result is not an exact value (Fauville et al., 2016), meaning that the user estimates, for example, the amount of meat they eat or how many car rides they take in one week. This is another example of the ways in which the outcomes of such calculations must be understood as approximations.

Using carbon footprint calculators in instruction

In the literature on the use of carbon footprint calculators and ecological footprint analyses in instructional settings, it has been documented that such tools serve as educational resources that contribute to making students aware of their environmental impact (Cordero, Todd, & Abellera, 2008; Kemppainen, Veurink, & Hein, 2007; McNichol et al., 2011; Hopkinson & James, 2010). For instance, in a study by Brody and Ryu (2006), ecological footprint analysis was used as a method for measuring whether a course in sustainable development influenced the consumption patterns of graduate students. In order to measure this, the authors compared the ecological footprints of 22 graduate students attending a course in sustainable development to those of 28 graduate students taking part in a development course with no focus on sustainability. A pre- and post-test design was used with the purpose of calculating the students' ecological footprints before and after attending their respective courses. The results showed that both groups of students had similar results in the pre-test. The results of the post-test, on the other hand, showed that the 22 students taking part in the development course on sustainability lowered their reported ecological footprint after the course, while this was not the case for the members of the other group, who instead increased their footprint. This finding points to the role of the tool in changing lifestyle behaviours.

In another study, Cordero, Todd, and Abellera (2008) explored college students' attitudes towards climate change. The study included approximately 400 participants from two different meteorology courses who took part in pre- and post-tests that featured questions about "1) the causes of global warming and ozone depletion, 2) the relationship between global warming and ozone depletion, and 3) the link between energy use and greenhouse gas emissions" (p. 866). During the period of time between the two tests, half the students in one of the two courses were involved in an ecological footprint activity in which they completed an online ecological footprint quiz. The students also completed a section on the ecological footprint which concerned what actions they could take to reduce their footprint; finally, they answered questions regarding the ways in which their actions were linked to their footprints. These students, who reported being surprised by the clear links between their personal lifestyle and global warming, claimed that they did not know that they had such a large impact on the environment. Furthermore, Cordero and colleagues (2008) concluded that compared to the students from the group that had not been involved in the ecological footprint activity, the group that had used the ecological footprint "significantly improved their understanding of the connection between personal energy use and global warming" (p. 871).

As I have pointed to previously in this section, a large number of studies related to students' use of digital technologies, and more specifically virtual labs, have set out to compare such activities with similar, more traditionally designed activities (e.g., hands-on labs and pen-and-paper activities). With respect to research on the implementation of carbon footprint calculators in instructional settings, however, such comparisons have not been made. The reason for this is that the carbon footprint calculator includes complex measurements of people's contributions to carbon dioxide emissions that would be very difficult to handle using pen and paper. In addition, such calculations would be too time-consuming and therefore not suitable as a classroom activity. Consequently, activities related to the use of carbon footprint calculators represent quite new learning activities for students (Brody & Ryu, 2006; Cordero et al., 2008; Hopkinson & James, 2010; Kemppainen et al., 2007; McNichol et al., 2011).

Since the carbon footprint calculator is a recent tool, research on its use by students as a part of instructional activities remains scarce. Fauville and colleagues' (2016) study of how European and U.S. high school students understood their personal environmental impact after having used the very same calculator as the one included in my research is one of the few examples. In this study, the analyses were based a) on how the students in the calculator estimate their carbon footprints, b) on online discussions about how the calculator supports students' reasoning about climate change, and c) on a questionnaire containing questions about the ways in which students express willingness to take action and change behaviours in order to lower their carbon dioxide emissions. Fauville et al. (2016) found that European students generally thought that they were more environmentally friendly than they actually were, whereas U.S. students estimated their environmental impact more accurately. The authors argued that this result might be connected to how the mass media often highlight the United States "as one of the greatest emitters of greenhouse gases" (p. 196) due to their reliance on fossil fuels. Europe, on the other hand, is often viewed as an actor in the forefront of international climate change work. Furthermore, analyses of the online discussions revealed that students expressed guilt when discovering that they had a higher carbon footprint than the average person in their country and pride when their environmental impact was below the average. These emotions imply that they expressed willingness to engage in climate change mitigation (cf. Mallett, Melchiori, & Strickroth, 2013, on the so-called eco-guilt related to carbon footprint). In addition to contributing to the field of research on carbon footprints, my thesis offers insights into how such a tool fosters different modes of reasoning about choice of actions in the context of personal lifestyle and about the nature of carbon footprint values through in-depth studies of students' discussions.

This chapter points to some features of how virtual tools imply new possibilities for learning. Virtual labs and carbon footprint calculators exemplify two rather recent tools; it is therefore valuable to explore the role they play in students' learning, particularly in environmental education in a school setting. The next chapter focuses on environmental education as a multidisciplinary academic subject involving different perspectives that emanate from natural science, social science, law, the humanities, and other areas. A prominent element of environmental education is learning about so-called socioscientific issues, which raise dilemmas that have no simple solution. Thus, in the next chapter, environmental education, students' learning about socioscientific issues, and science literacy are discussed.

3. Environmental education as an instructional challenge

This chapter presents a brief overview of environmental education and the implementation of this rather new curricular field in schools, followed by examples of studies examining how students analyse and negotiate socioscientific issues. Finally, there is a discussion about science literacy in inquiry-based learning activities and the instructional challenges of teaching students to learn *about* inquiry.

Environmental education

Even if environmental education may be regarded as a relatively new school subject in a more practical sense, it is not an entirely new issue in education. For example, Jean-Jacques Rousseau, John Dewey, and Maria Montessori, in different ways, highlighted the need to include topics that concern the nature and the environment in instruction (Fauville et al., 2014; Palmer, 1998). In recent decades, however, this field has become an increasingly important part of schooling in many parts of the world. In the 1970s, UNESCO, together with the United Nations Environment Programme (UNEP), introduced the International Environmental Education Programme (IEEP). The IEEP put together a list of targets with the purpose of making people throughout the world aware of the environment and the environmental challenges we face. These targets emphasize the importance of providing people with "knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones" (UNESCO, 1975, p. 40). Two years later, this list of targets was extended to include the important element of making the relationships between individual and collective activities and their impact on the environment transparent. In addition, the interdisciplinary nature of environmental education was acknowledged, thereby recognizing that environmental education requires insight into many fields (UNESCO, 1977). Since the 1970s, the issue of educating people about environmental topics and sustainable development has been further discussed at several international meetings (Combes, 2005; Gough, 2014; UNESCO, 2004). This acknowledgement mirrors the ways in which environmental education has been implemented in the educational systems in European Union countries, where most countries integrate environmental education in subjects such as science, geography, and/or technology (Stokes et al., 2001). Only at the upper secondary level do curricula address environmental education in more specific ways through specialized courses and programmes.

As mentioned in the introductory chapter, and in line with how UNESCO defines the aim of environmental education, the Swedish national curriculum for the compulsory school, preschool class and the recreation centre (2011) stresses the importance of preparing students to take an active role in supporting sustainable development. Consequently, there is an emphasis on the environmental perspective and the need for students to learn about environmental topics:

> Through an environmental perspective, they gain the opportunity to take responsibility for an environment they can directly influence themselves and to gain a personal approach to global environmental issues. The teaching will shed light on how society functions and the way we live and work can be adapted to create sustainable development. (Skolverket,[10] 2011, p. 9)

One way of implementing such a curricular goal is to target students' awareness regarding their personal environmental impact. As pointed out before, currently there are many tools that are designed to make the personal environmental impact explicit for people, such as the carbon footprint calculator used by the students' in my research. However, even if such tools facilitate awareness at an individual level, subsequent challenges remain in terms of how to foster an understanding of what this means on systemic and global levels, and how personal actions have consequences on the climate in general. This kind of holistic view of environmental awareness requires systems thinking (Fauville et al., 2016; Sinatra, Kardash, Taasoobshirazi, & Lombardi, 2011). Sterman (1994) described systems thinking as

> the ability to see the world as a complex system, in which we understand that "you can't just do one thing," that "everything is connected to everything else." If people have a holistic worldview, it is argued, they would then act in consonance with the long-term best interests of the system as a whole. (p. 291)

[10] The Swedish National Agency for Education

In the present research, the curricular context of the four studies concerns climate change and, more specifically, ocean acidification and carbon dioxide emissions. Thus, these environmental topics are examples of issues that need to be understood as a part of larger systems (e.g., ecosystems and the carbon cycle). For instance, in the virtual lab, the students get to study ocean acidification and its consequences through a virtual experiment on sea urchin larvae (see Chapter 5). The effects of ocean acidification on sea urchin larvae have consequences on the adult sea urchin population, which in turn will have implications for sea otters that depend on urchins for food as well as for other animals and algae in the sea urchin food web and, ultimately, for the entire ecosystem. The same kind of systems thinking can be found in the observation that students need to develop an understanding of the environmental impact of their actions not only from a personal perspective but also from a global perspective. That is, if the students go on holiday by airplane, this does not only have consequences for their personal carbon footprint values but also for the climate at large. The difficulty of linking their carbon footprint results to a systemic level is discussed in Study 3, when the students defend their high emission values in transport due to air travel by pointing to their lower emissions in the other areas.

One way of dealing with the challenges of contextualizing environmental issues on a systemic level in instruction is to approach them by highlighting the socioscientific aspects and introducing activities that include the negotiation of these different aspects (Sadler, 2009; Sternäng & Lundholm, 2011). The next section exemplifies some research studies on learning about socioscientific issues in instructional settings as a means for understanding sustainability and environmental change.

Learning through analysing socioscientific issues

Socioscientific issues are open-ended; they have several possible answers and solutions (Mäkitalo, Jakobsson, & Säljö, 2009; Sadler et al., 2007). Furthermore, socioscientific issues are expected to provide contexts in which students can explore ethical principles, negotiate social and political dilemmas, and consider decisions that stem from scientific, economic, political, and ethical tensions (Dawson, 2015; Sadler et al., 2007; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005; Åberg, 2015). Examples of socioscientific issues or dilemmas that are often used in instruction include global warming (Jakobsson et al., 2009), the implications of genetically modified organisms (Christenson & Chang Rundgren, 2015), and genetic testing (Dawson & Venville, 2010). These issues require students to position themselves

> as active contributors to society with competencies and willingness to employ scientific ideas and processes, understandings about science and social knowledge (e.g. ideas about economic and ethical influences) to issues and problems that affect their lives. (Sadler, 2009, p. 12)

This means that students not only need to understand the topics from different disciplinary angles; rather, the issues as such are also often open-ended and sometimes highly contested. Thus, working with these kinds of topics serves to prepare students for active participation in society by expecting them to make informed judgements that they can argue for (Sadler, 2009; Sternäng & Lundholm, 2011).

In research on students' learning through grappling with socioscientific issues, one dominant approach focuses on assessments of students' content knowledge and argumentation quality (e.g., Christenson & Chang Rundgren, 2015; Hogan, 2002; Sadler & Donnelly, 2006). One such study, conducted by Dawson (2015), included over 400 students (14–15 years of age) who were assessed on their understanding of the greenhouse effect and climate change.[11] The author argued that the greenhouse effect and climate change are socioscientific issues that often cause confusion among students; for instance, a common misconception is that the ozone layer and the greenhouse effect are connected to each other. Based on empirical data generated through questionnaires and interviews, Dawson explored the students' understanding

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[11] Concepts such as the greenhouse effect, climate change, and global warming are used and discussed in different ways; there are scientific definitions and, furthermore, media interpretations. The following text lists the scientific definitions of these terms.

The *greenhouse effect* is defined as the natural effect that makes it possible for people to live on Earth. Without the natural greenhouse effect the average temperature on Earth would be much colder, too cold for people to survive. In addition, there is an anthropogenic effect, which is caused by human activity through the burning of fossil fuels.

Global warming is a concept that concerns the increased temperature that is caused by the anthropogenic greenhouse effect (IPCC, 2014).

Climate change refers to "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulation of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use." (IPCC, 2014, p. 1255).

of these environmental topics in order "to identify their alternative conceptions about climate change science and provide a baseline for more effective teaching" (p. 1024). The same two questions were posed in both the questionnaires and the interviews: 1) what is the greenhouse effect? and 2) what is climate change? The greenhouse effect was defined by the author as involving "greenhouse gases that cause an increase in temperature" and climate change as "a change in climate related to the greenhouse effect" (pp. 1031–1032). These two definitions were the expected, and in this sense the correct, answers to the questions. The answers were categorized in terms of content correctness. The analysis demonstrated that the students found it difficult to provide correct definitions of both the greenhouse effect and climate change. Furthermore, based on the students' definitions of these two environmental topics, the author identified alternative conceptions that demonstrated the students' confusion regarding "the greenhouse effect and the ozone layer; the nature of greenhouse gases, types of radiation; differences between weather and climate and air pollution" (p. 1040). This study illustrates the complexity involved in learning about socioscientific issues.

It should be noted, however, that studies assessing students' content knowledge and argumentation quality often introduce quite difficult questions about complex socioscientific issues (e.g., "What is the greenhouse effect?" or "What is climate change?" which were used in Dawson's study). This complexity is discussed in a study by Jakobsson et al. (2009), in which the authors analysed students' reasoning about the greenhouse effect while engaged in project work that stretched over six weeks. The interest of the study was to investigate how the students used and appropriated a scientific language over time. Jakobsson et al. (2009) stressed that there are some problems involved when students are asked to define such broad and open questions, such as what the greenhouse effect "is." The scientific definition implies that there is both a natural and an anthropogenic (i.e., caused by human activities) greenhouse effect. Accordingly, when posing such a question, it is challenging for students to realize what they should focus on in their answer. Another aspect of this is that "[i]t is difficult for students to predict how extensive their reasoning should be in order to be considered satisfactory" (Jakobsson et al., 2009, p. 982). In her study, Dawson (2015) pointed to the existing critique of exclusively using questionnaire data when exploring how students understand climate change and the greenhouse effect by referring to the study by Jakobsson et al. (2009). Furthermore, as described earlier, Dawson utilized both questionnaire data and interview data, where the latter were used as a complement to the questionnaires with the argument that "questionnaires are insufficient for students to state all that they know" (2015, p. 1028). I would argue, however, that what is problematic here, which was also discussed by Jakobsson et al. (2009), is how questions in these areas are formulated. Of course, it is much more demanding for students to deliver an answer to open and complex problems of this kind, and there is an added complexity when one has to do it in writing. The challenges involved in tasks that require students to give written responses are further discussed in the next section. Nevertheless, the challenge of how to approach a question of describing the greenhouse effect is still an issue in Dawson's study, since the formulation of the problem is the same in both the questionnaire and the interview. That is to say, the difficulty of how to approach this broad question remains, regardless of whether it is posed in written or in oral form. Consequently, there is a difference between studies that, in line with Dawson (2015), investigate students' knowledge about socioscientific issues through assessing their answers in test situations and studies exploring how students deal with such topics in interactions in classroom activities over a period of time (e.g., Jakobsson et al., 2009).

Accordingly, and in line with the study by Jakobsson and colleagues (2009), another set of research studies in the context of studying classroom works with socioscientific issues is studies that focus on the processes of student interaction when engaging in such learning activities (e.g., Furberg & Ludvigsen, 2008; Jakobsson et al., 2009; Säljö, Mäkitalo, & Jakobsson, 2011). For instance, Furberg and Ludvigsen (2008) aimed "to examine students' meaning-making of socio-scientific issues in ICT-mediated argumentation settings" (p. 1777). The focus of the analyses was on the collaboration between two students who were writing an article on the topic of gene technology. By studying the interaction between the two students (who were video recorded), Furberg and Ludvigsen found that they made meaning of gene technology in different ways. One way was to search for scientific explanations of gene technology. Another manner in which the students tried to make meaning was to focus on social consequences of the concept of gene modification. The authors demonstrate how one of the students "brought in elements from different discourses, and also that she framed the gene modification topic as a debate" (p. 1790). However, the findings from the study also revealed that the students oriented their work towards fact-finding.

The conclusion was that despite the observation that "the students' end product had the characteristics of a fact-finding orientation, it is important to recognize the amount of valid cognitive work that can lie behind their end product" (p. 1793). Through their research, Furberg and Ludvigsen illustrated that by studying students' interactions while working in ICT-mediated argumentation settings, it is possible to get access to significant parts of their meaning-making processes.

In summary, studying students' answer to broad and open questions provides knowledge about how students interpret and understand them. Alternatively, studies on students' reasoning while engaged in group discussions contribute to insights into how they make meaning in the context of complex socioscientific issues and how, and if, they are on their way to appropriating a scientific language (see also Jakobsson et al., 2009).

The first empirical study of my thesis concerns an analysis of students' written answers to a problem-solving question in which the students were required to suggest a design of an experiment addressing a specific environmental issue (for an overview of the results from Study 1, see Chapter 7). Studies 2, 3, and 4 investigate students' interactions while engaged in problem solving activities in the context of analysing socioscientific issues. One way to examine students' ongoing work related to socioscientific issues is to base such studies on how the students develop their ability to talk science in inquiry-based activities (Dawson, 2015; Sadler et al., 2007; Sadler & Donnelly, 2006), which is discussed in the following section.

Talking science in inquiry-based learning activities

Learning about socioscientific issues in schools is frequently based on activities supported by an inquiry-based pedagogy (Minner, Levy, & Century, 2010). The ideas of inquiry learning were first articulated by John Dewey in his early works (1997[12]). An assumption behind these ideas is that if students learn how scientists formulate questions, how they study them and draw conclusions from their work, the students will have resources for understanding the nature of science and scientific knowledge. That is, they will get insights into how research results are produced and validated rather

[12] This was pointed out by Dewey already in his first version of *Democracy and education. An introduction to the philosophy of education* (2016). New York, NY: The Macmillan Company.

than learning only about the end products of the scientific work. As argued in the introduction, Dewey's ideas behind the concept of inquiry serve as an analytical tool for understanding students' problem solving activities. This is further detailed in Chapter 4.

Various studies have pointed to the challenges that occur when students are to learn both how to *do* experiments in a practical sense and to learn *about* experiments as a method for investigating issues (e.g., Bybee, 2000; Gyllenpalm, 2010; Lager-Nyqvist, Wickman, Lundegård, J. S. Lederman, & N. G. Lederman, 2011). According to Abd-El-Khalick et al. (2004); however, it is

> often believed that students will develop understandings about scientific inquiry and NOS [nature of science] simply by doing science. Having students experience authentic inquiry is absolutely necessary, but not sufficient. (p. 403)

According to these authors, for students to develop an understanding of scientific inquiry, the "doing science" element should be followed by activities which require them to reflect on "the nature of the knowledge produced" (p. 403). Thus, both doing inquiry and learning about inquiry are important elements in the process of developing an understanding about experiments and inquiry that need to be practised repeatedly (Hart, Mullhall, Berry, Loughran, & Gunstone, 2000). For example, a study by Lager-Nyqvist and colleagues (2011) examined to what extent students in a science-learning context are able to formulate questions that are possible to investigate. Being able to formulate questions that are possible to investigate may be seen as a valuable indicator of understanding the nature of scientific inquiry. Lager-Nyqvist and colleagues found, among other things, that the concrete context in which the students were to communicate about the nature of scientific inquiry had a clear effect on their capacity to formulate a question that would be possible to answer through research. In the study, 32 groups of pupils (aged 12–13 years) were to plan an investigation that would answer the question of whether ice cubes would melt more quickly if they were covered in fabric or, alternatively, if they would melt more quickly in open air. The results illustrated that the pupils' skills in formulating questions that would be possible to investigate in a scientific sense in this specific context were dependent on the situation in which the students were working, that is, if they were to formulate such questions a) in writing, b) in verbal form, or c) while conducting the investigation. To formulate questions in writing was shown to be a difficult task, while doing it in hands-on experiment situations was much easier. The authors argued that the task of formulating questions in writing that are possible to investigate empirically is rather abstract for students; they are not used to formulating questions in this way in a science-learning context but rather are used to answering them. However, when engaged in a practice of investigating and manipulating materials, the task of formulating questions in situ becomes much easier.

Learning through inquiry-based instruction, then, implies that students need to learn both the language and the procedures for how to observe and to codify the world in scientifically relevant manners (Wickman, 2004). As Gyllenpalm (2010) put it,

> [k]nowledge, both in terms of learning to do and learning about inquiry, involves acquiring a language in order to talk and communicate about investigations and their results. (p. 19)

This could be understood as an issue of how to become literate in school science matters. The term *science literacy* was first used in the late 1950s (DeBoer, 2000), and it has since been used in the public debate on education. It is also possible to find the term in research studies, policy documents, curricula, etc. (Roberts, 2007). Various studies point out that the concepts *science literacy* and *scientific literacy* have different meanings, but there are also studies that do not emphasize this difference (Mayer, 2002). For studies that do point to the different meanings of these terms, science literacy implies that people have a general knowledge about issues within fields of science and that they are conversant with science and scientific knowledge. The term scientific literacy, on the other hand, emphasizes a civic-directed literacy, which implies that people are familiar with issues in a range of areas and that they understand and are able to apply these skills as citizens in a modern society (see Mayer, 2002; Roberts & Bybee, 2014). Throughout this thesis, the term *science literacy* is used in discussions relating to how students work with inquiry-based learning activities and when they reason about the acidification of the ocean. The term *scientific literacy* is used when socioscientific issues are addressed, for example, when the students reason about the environmental impacts of their everyday actions.

Science education implies that students meet and have to appropriate scientific concepts and discourse. In order for students to become science literate, however, it is not enough to appropriate a specific terminology and to learn about scientific methods and inquiry. Learning science also implies developing an ability to use textual and multimodal resources that are relevant in scientific discourse and practices. Science literacy requires that the learner understands that content and arguments are presented in a range of modalities, for example in the form of written text, diagrams, tables, pictures, formulae, etc. Thus, for students to become science literate, they need to develop an understanding of how to use scientific concepts as well as how to connect various modalities and to translate one modality into another (Lemke, 2004; Wickman, 2004). In the present research, the issues of students' emerging science literacy are discussed in Studies 1 and 4. In Study 1, the students are required to outline an experiment that is relevant for addressing an environmental problem. The interest was to ascertain to what extent they would use scientific concepts such as sample, control group, observation, and comparison when outlining their experiment and if they could identify how cause-and-effect relationships might be analysed. In Study 4, the students discuss the validity and possible shortcomings of claims made in the abstracts of two scientific articles and are required to write reports commenting on the organization of the experiment.

As opposed to many tools available, the digital tools and related student activities investigated in this thesis have deliberately been developed with the purpose of supporting students when working with socioscientific issues regarding environmental issues and climate change.[13] Here, virtual labs and carbon footprint calculators may be viewed as yet another set of mediating resources to support inquiry learning.

In the next chapter, I elaborate on the sociocultural perspective that underpins this research. In addition, Dewey's (1938) view of learning through inquiry is further discussed.

[13] http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r1b/i2s.php#

4. Theoretical perspective: Learning, tools and practices

This chapter includes a discussion of some of the premises of the sociocultural perspective on learning and, in addition, of Dewey's ideas of learning through inquiry. Through the key concepts of cultural tools, mediation, mediated action, and appropriation, the sociocultural approach to analysing learning in social practices is discussed.

Learning, cultural tools and situated practices

The situated nature of human reasoning is a basic premise for research on learning and thinking from a sociocultural perspective. This implies that knowledge and learning are regarded as manifested in and emerging from participation in social practices (Lave & Wenger, 1991; Säljö, 2005). Central to this framework is also the idea that the individual, through appropriation of cultural tools, learns to master important elements of the social memory (Säljö, 2005; Vygotsky, 1978; Wertsch, 1998). In this sense, the manipulation of cultural tools contributes to experiences that represent a form of social memory, which is essential to the continuity of an individual's learning and development. Learning, then, becomes a matter of being able to utilize cultural tools in situated practices in relevant and productive manners. As argued by Säljö (2010):

> We cannot look for human competences solely in our minds or bodies. Instead, our knowledge is expressed in our abilities to merge and collaborate with external tools and to integrate them into the flow of our doings, whether these are intellectual, physical or mixed. (p. 63)

This implies that the tools mediate the world for us in different activities (Säljö, 2005). Consequently, the tools involved in the students' environmental science activities in the present study are seen as mediating resources, or mediational means (Wertsch, 2007) that they deploy to understand and argue about ocean acidification and climate change.

Mediation and mediated action

Cultural tools are mediators in human action; this is a cornerstone of a sociocultural approach to human learning and development. The concept of mediated action implies that there is "a kind of natural link between action, including mental action, and the cultural, institutional, and historical contexts in which such action occurs" (Wertsch, 1998, p. 24). The virtual lab is an example of such mediated activity, where the actions of students performing an experiment constitute a situated practice within an institutional setting. The virtual lab incorporates and exploits scientific language and other tools, such as diagrams, tables, and equations; additionally, there are representations of lab equipment in the interface that the students use in their work (Lemke, 1990). In this manner, the virtual lab incorporates a variety of mediational means.

In addition to the interest in studying virtual labs as contexts for learning about a specific topic (i.e., ocean acidification), this study focuses on the issue of whether, and to what extent, the students develop an understanding of the logic of scientific work, especially what constitutes an experiment (in the scientific sense). At this level, thus, the virtual lab is an arena in which students can learn about the principles and procedures of research and about how aspects of ocean acidification may be addressed in a scientific manner by formulating hypotheses and testing them in the laboratory context. When operating with the virtual lab, the students will engage in activities such as formulating hypotheses, designing experiments and carrying them through, and measuring samples of marine organisms. Since experiments of this kind are difficult, or even impossible, to perform in a traditional school lab, the virtual lab, in many cases, visualizes and mediates something that the students otherwise could not observe or participate in.

Furthermore, through the use of cultural tools such as a virtual lab and a carbon footprint calculator, the students get access to new ways of talking about and understanding ocean acidification and carbon dioxide emissions. In a Vygotskian (1997) view, what we see here is how a cultural tool "recreates, reconstructs the whole structure of behavior" (p. 87). In other words, through using tools, the ways in which we think and act are restructured. Wertsch (1998) presented an example of how the use of cultural tools can help us solve different problems that we encounter in our daily lives. The example involves the task of multiplying 343 by 822. For most people, it would be impossible to solve such a mathematical problem by mental arithmetic. However, if people use a calculator or organize the numbers on pen and paper, they are able to solve the problem. Thus, the organization of the numbers, supported by the use of pen and paper or the calculator, then, "is doing some of the thinking involved" (p. 29).

Let us take the example of the use of a carbon footprint calculator to illustrate this Vygotskian idea further. A carbon footprint calculator invites people to measure the carbon dioxide emissions of everyday activities. Using such a tool implies that people get insights into their carbon footprints mediated in kilograms or in pounds. As a next step, they may compare their own footprint by relating it to the average impact of fellow citizens in their country or in other parts of the world. Here, people, through using the tool, obtain resources with which to compare and analyse their impact on the environment without needing to know very much about the underlying parameters on which these values build. Put differently, in order to be able to work with the carbon footprint calculator, people do not necessarily need to have knowledge about the gases and levels that are included in the calculations. This makes people, as Wertsch (1998) put it, sometimes "unreflective, if not ignorant, consumers of a cultural tool" (p. 29). Consequently, insight and understanding arise from reasoning, where the tools contribute to transforming abstract functions into explicit and manageable knowledge.

Cultural tools, therefore, allow students to articulate knowledge through comparisons and other analytical exercises in ways they would not be able to achieve without the tools (Vygotsky, 1997). As Vygotsky described it, "[t]he inclusion of a tool /…/ abolishes and makes unnecessary a number of natural processes, whose work is [now] done by the tool" (p. 87).

An interesting element of mediating resources such as virtual labs and carbon footprint calculators in the present study is that they build on scientific and technical work that, to a large extent, is *blackboxed* (Latour, 1999) for the user. Latour defined *blackboxing* as

> An expression from the sociology of science that refers to the way scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become. (p. 304)

Accordingly, and as is illustrated in Studies 2 and 3 in this thesis, there are several features in the design of the virtual lab and the carbon footprint calculator that the users do not notice when they engage with them. The user operates through the interface and is focused on the functionalities, and features such as the programming or the databases utilized are not attended to. However, Latour argued, when people encounter difficulties or run into problems while using such tools or technologies, they will become aware of their blackboxed nature. Latour uses the example of an overhead projector when illustrating the blackboxed nature of technologies. As long as the projector works, people take the tool for granted and as "completely determined by its function" (p. 183). It is when the projector breaks down that people, in their work of trying to solve the problem with the tool, "remember that the projector is made of several parts, each with its role and function and its relatively independent goals" (p. 183). There are, of course, a large number of features that are blackboxed in technologies. In the virtual lab, for example, the information behind the different procedures in the experiment, the order of those procedures, the measurements that graphs on carbon dioxide emissions in air and water build on. To unpack all aspects of the built-in technologies and information in a digital tool is, however, not possible, nor is it desirable.

Appropriating cultural tools

The term appropriation, from a sociocultural perspective, refers to the process by which people increase their skills in using cultural tools through participating in various social practices. In a Vygotskian view, people use cultural tools or signs all the time, and at first they use the tools without fully mastering them. However, after some exposure to the tool, and through collaboration with more experienced people or experts, they may come "to understand the meaning and functional significance of the sign forms that one has been using all along" (Wertsch, 2007, p. 186). The goal of instruction, then,

> is to encourage students to master the use of cultural tools. Becoming more expert means being socialized into an existing social order, characterized by an existing set of cultural tools, and expertise is reflected in the ability to use these tools flexibly and fluently. (Wertsch, 2007, p. 190)

A central element when talking about the concept of appropriation is "the relationship of agents to meditational means" (Wertsch, 1998, p. 53), that is, learning takes place through participation with other people and with cultural tools or meditational means. Accordingly, as Wertsch put it, appropriation is the process "of taking something that belongs to others and making it one's own" (p. 53). There are a number of studies that used the concept of appropriation to study the processes of students' learning activities (e.g., Eriksson, 2014; Erstad, 2011; Säljö et al., 2011). For example, in their study, Säljö et al. (2011) used the concept of appropriation to identify how students, through interaction, appropriate, in the Vygotskian sense, scientific concepts and how they use such concepts as analytical tools in debates and discussions. The study was based on video recordings of a group of four students who, for a period of four weeks, work on an assignment concerning the greenhouse effect and global warming. In their discussions, the students negotiate about the greenhouse effect as something natural or anthropogenic. In media, the anthropogenic effect is often focused on discussions connected to the greenhouse effect. From a scientific perspective, however, the greenhouse effect is something natural. One of the group members shows, already from the start, an understanding of the relationships between the greenhouse effect and global warming, as she argues that the greenhouse effect is essential to most life on earth. In contrast, two of the group members stress that the greenhouse effect has not always existed; it is the result of human activities, they argue. However, through studying the group members' discussions over time, Säljö and colleagues illustrated how the two students, who from the beginning had denied that the greenhouse effect is natural, changed their way of reasoning about the issue. That is, the two students developed their understanding of the greenhouse effect through reasoning and discussing with a group member who could be considered a more competent "peer," to use Vygotskian language.

A similar example from my research, taken from Study 2, is when students used the teacher's introductory lesson as a resource for understanding concepts of ocean acidification. In Study 2, the students worked with the Acid Ocean Virtual Lab. The first part of the lab presents some basic facts about ocean acidification. It also contains discussion questions for the students to answer regarding, for example, the possible impact of acidification on marine organisms such as sea urchin larvae. In his introduction, the teacher touched on these aspects. The results illustrate how the students, through re-using the teacher's formulations, appropriated certain elements of his reasoning for their own use and thus made it a part of their own argumentation. (This is discussed in more detail on the pages 84-85 of Chapter 7).

Learning through problem solving

As I have already pointed out, in this research, students participated in problem-based learning activities, that is, they engaged in what Dewey (1938) referred to as "inquiry," which is a central concept in the pragmatist approach that he developed (see below). Greeno et al. (1996) argued that in both the sociocultural and the pragmatist perspective, learning and development are construed as taking place through interaction between people and between people and artefacts in situated practices. Thus, integrating these perspectives is consistent with the classification of the traditions in educational theories according to Greeno and colleagues. The classification implies that the sociocultural perspective and the pragmatist perspective belong to the situative/pragmatist-sociohistoric view, in which knowledge is regarded as "distributed among people and their environments, including the objects, artefacts, tools, books, and the communities of which they are a part" (p. 17). As mentioned earlier, in this research, the sociocultural perspective provides a rationale for analysing how cultural tools mediate understandings of scientific methods on the one hand and, on the other, environmental issues related to climate change. In addition, the students' problem solving activities are analysed through the concept of inquiry as described from Dewey's (1938) pragmatist perspective. The literature describes many studies which have integrated these two perspectives in analyses of teaching and learning (e.g., Gyllenpalm, 2010; Jakobson & Wickman, 2015; Wickman, 2006).

As discussed in Chapter 3, teachers often use some kind of inquiry-based learning in the contexts of addressing socioscientific issues. In the case of this research, the virtual lab and the carbon footprint calculator are tools that have been developed to support such inquiry-based learning (cf. de Jong, 2006; Furberg, 2010, 2016, on how computer-supported collaborative learning can support inquiry processes). In this sense, the concept of inquiry serves as an analytical tool for understanding students' problem solving activities.

Consequently, in this research, the concept of inquiry is not used to describe an instructional method (Säljö, 2015); rather, this research investigate whether the students engage in inquiry while working with problem solving tasks. This means that my research target how the students understand a problem, if they can formulate a problem that would be possible to investigate in a scientific manner, how they interpret data, and similar issues. Thus, inquiry is used to conceptualize how the students learn through problem solving activities.

Dewey (1995) criticized the ways in which science was taught in schools. One of his arguments was that "science teaching has suffered because science has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject-matter" (p. 394). What Dewey objected to was that scientific instruction was heavily centred on teaching students concepts, facts, laws, and procedures of laboratory work, etc. without giving enough attention to how problem solving and scientific work generate knowledge. For instance, Dewey (1995) argued that students practise laboratory work without fully understanding that such procedures have something to do "with constructing beliefs that are alone worthy of the title of knowledge" (p. 395). Thus, in order for students to be able to formulate hypotheses, to select or reject data, and so on, they would need to identify "*what* the problem and problems are" (Dewey, 1938, p. 108).

The processes of identifying what the problem is and the ways in which it may be investigated are central elements of inquiry (Talisse, 2002). Dewey defined inquiry as "the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole" (1938, pp. 104–105). For instance, in Study 1, the students were to produce a written answer describing an experiment that would provide information if, and to what extent, changes in water quality caused by a fish hatchery could affect the growth of corals (for details, see p. 65). Thus, to answer such a question, the students would need to understand how to convert the problem into a relevant study or experiment. Put differently, questions of this kind prompt students to engage in inquiry, and in this manner, Dewey argued, people would learn what characterizes the production of scientific knowledge. Dewey also maintained that learning such generic skills that carry across contexts and situations is especially important in situations where we see a rapid growth of scientific knowledge and when this kind of knowledge undergoes change (Dewey, 1997). It should be noted that this was a line of argumentation that Dewey pursued almost a century ago. If we consider the current rapid expansion of scientific knowledge, Dewey's claim seems even more relevant today (Säljö, 2015).

The next chapter describes some of the details of the technology-rich learning contexts of my studies. The empirical materials that form the basis of the four studies in the thesis and the two specific digital tools, the Acid Ocean Virtual Lab and the Carbon Footprint Calculator, are presented.

5. Research context

This chapter describes the settings that have been studied as well as the two types of core data, questionnaires, and video documentations on which the thesis is built. These core data have generated four empirical materials, all of which have been analysed. Finally, there is a presentation of the two specific tools included in the research: the Acid Ocean Virtual Lab and the carbon footprint calculator.

The settings

As is mentioned in Chapter 1, the present research is a part of an extensive research project called Inquiry-to-Insight (I2I). The I2I project is a large-scale, binational collaboration between schools in the United States and Sweden dealing with issues of climate change. The questionnaire data and the video data included in the thesis were generated from students' work with the virtual lab, the carbon footprint calculator, and assignments that I2I scientists designed.

The questionnaire data are authentic in nature in the sense that the classroom activities did not include interventions or participation from researchers or the use of any other extra resources or support. There are, of course, methodological difficulties linked to this kind of naturalistic empirical material. For instance, I did not have access to data about how the teachers introduced the virtual lab or how the students used the virtual lab in the classroom situation. The strength, however, is that this data set is unique, containing more than 500 students' answers to a pre- and post-test in a context where the virtual lab has been used in a regular instructional setting. Not having access to extensive information about the setting is compensated for by the continuation of my research with additional data through video documentation in the Swedish setting of students working with the virtual lab. It was therefore decided to analyse these data and the American students' written answers to the pre- and post-test in spite of the fact that we did not have access to process data (Study 1). One specific question in the pre- and post-test was analysed. This was the only open-ended, problem solving question on the test, and it required the students to outline an experiment. All other questions in the tests were multiple-choice. The study is further elaborated on in the next chapter.

The additional core data, consisting of video recordings, gave insights into the processes of how the students worked with the virtual lab in ongoing activities (Study 2), in what ways they discussed their personal carbon footprints (Study 3), how they reasoned about experiments, and how they interpreted and managed to deconstruct scientific claims (Study 4). Accordingly, these research questions were studied in the video data that document a Swedish upper secondary class (aged 16–17 years) when engaged in environmental education activities. Three people planned and generated the video data: one researcher from the research project, myself, and one technical expert on video recording from the LinCS-lab.[14] In this way, the video data covered the students' process of engaging with the virtual tools; therefore, they are in a sense also more controlled compared to the data that were provided through the I2I project.

The teacher of the Swedish upper secondary class was a part of the I2I project and collaborated with marine biologists on the project. We contacted the teacher and discussed how to best conduct the study. The class that was a part of our study worked during one school year with the virtual tools, along with written assignments aimed at stimulating students to collaboratively reason about research and environmental issues related to climate change. The students also visited a marine station, where they met with marine biologists in order to learn about ongoing experiments being conducted at the station. The curricular context was marine biology, a subject of student choice. The teacher and the students were informed about the general interest of the research. We made it clear to the students that we were not interested in assessing their individual work, nor were we involved in grading or in any kind of evaluation of the various activities and assignments. We explained that, instead, we were interested in their ways of reasoning and working in the classroom. In order to trigger the students to discuss and to externalize their reasoning, we asked them to work in groups of two to four students of their own choice. The teacher in the Swedish school was introduced to the virtual lab and to the carbon footprint calculator through his collaboration with marine scientists. However, the teacher used the tools independently and as a

[14] http://lincs.gu.se/research_organisation/lincs_lab

part of his regular teaching. Furthermore, it was the teacher who planned and organized the lessons that we recorded. Thus, we were not involved in this work. In this sense, the studies included in the thesis could be regarded as naturalistic studies of ongoing school activities organized by a teacher within a regular classroom setting.

The next section presents the two types of core data utilized: questionnaires and video documentation. The video documentation took place on three different occasions during a period of one school year. These materials are described in the following section.

Four empirical materials

As mentioned previously, the questionnaire data were analysed in Study 1, and Studies 2, 3, and 4 utilized the video documentation. The virtual lab and the carbon footprint calculator comprise a part of the four different empirical materials in different ways (for an overview of the empirical materials, see Table 1). The empirical material of Study 1 is the open question on the pre- and a post-test that more than 500 American students answered. During the period of time between the two tests, they worked with the virtual lab under the auspices of their teacher. The video-recorded activity in Study 2 relates to students' work with the virtual lab in situ in the classroom. The empirical material in Study 3 consists of video recordings of students' group discussions after having used the carbon footprint calculator as a part of regular education. In this manner, the virtual tools played a central part in Studies 1, 2, and 3. Study 4 does not explicitly include activities with the virtual tools. However, during the school year, the students were involved in activities that included the use of the virtual lab and the carbon footprint calculator. In this study, the students read and evaluated previous research on ocean acidification made by others. Table 1 illustrates the empirical materials, the type of data, and the school activity that occurred in each study.

Table 1: Overview of the empirical materials

	Study 1	Study 2	Study 3	Study 4
Empirical material	Students' written answers in a pre- and post-intervention study	Activities of students' in situ work with the virtual lab	Students' discussions related to the use of a carbon footprint calculator	Students' discussions evaluating research and writing reports
Type of data	Product data: questionnaires	Process data: video documentation	Process data: video documentation	Process data: video documentation
School activity	Pre-test Virtual lab Post-test	Virtual lab activities in groups	Calculate carbon footprint individually followed by group discussions	Evaluating research and writing reports in groups

Studies 1, 2, and 3 are related to the first research question, which concerns how the digital tools co-determine the activities and students' reasoning and learning about scientific knowledge relevant to understanding environmental topics. The second research question is connected to studies 1 and 4, as it addresses what implications the use of digital tools have for the development of science literacy. The different materials are introduced in the following text.

1. Students' written answers to a pre- and post-intervention survey. Over 500 American students participated in this activity. Two weeks after completing a pre-test, the students completed a post-test. The tests consisted of 17 questions about ocean acidification. Sixteen questions were multiple-choice,[15] and one question was open-ended. In the weeks between the two tests, students worked independently with the virtual lab. In this extensive material, the open-ended question was chosen for analysis. The question asked the students to suggest an experiment to ascertain the consequences of a change in water quality on the marine environment. This problem-solving question required an answer that resembled the type of experiment students had worked with in the virtual lab.

2. Activities of students' in situ work with the virtual lab. In this material, 19 students were observed while working in lab sessions in the Acid Ocean

[15] Examples of multiple-choice questions and the selection of answers given in the two tests are "Ocean acidification means that the pH is: Decreasing – Increasing – Not affected – I don't know" and "Ocean acidification causes the following changes: An increase in the amount of carbonate in the ocean – A decrease in the amount of carbonate in the ocean – No change in the amount of carbonate in the ocean – I don't know."

Virtual Lab, where they practised experimentation in a virtual lab environment. The instructional context was teaching about ocean acidification and its impact on marine organisms as an aspect of climate change. The students worked with these issues during one half-day lesson. The teacher started the lesson by giving a short introduction on ocean acidification. In his introduction, he talked about how carbon dioxide emissions lead to a decrease of pH levels in oceans and what consequences this would have on marine organisms. In the virtual lab, the students practised an experiment in which they studied the growth of sea urchin larvae in water with different pH levels. In order to be able to analyse what the students said and how they understood information and procedures in the virtual lab, we asked them to work in groups of three to four members. The teacher's introduction to the lesson and the students' virtual lab activities were video recorded.

3. Students' discussions related to the use of a carbon footprint calculator. This material consists of video recordings from one lesson in which 15 students participated. In the first part of the lesson, the students worked individually with the carbon footprint calculator to calculate their personal carbon footprint. This activity was not documented, since the students worked individually on their own computers, and little interaction took place. The second part of the lesson included the students' discussions and analyses of their personal carbon footprints, which were guided by questions formulated by marine biologists from the I2I project. For instance, students analysed their lifestyle activities and choices regarding transportation, eating habits, etc. The students worked in groups of three to four members. These group discussions were video recorded.

4. Students' discussions when evaluating research and writing reports. This material consists of video recordings from one lesson in which students worked with an assignment to critically scrutinize scientific claims in two short article abstracts. Marine biologists from the I2I project formulated the assignment, which included two texts designed as research article abstracts. The abstracts concerned the relation between changes in pH in the ocean and an observed increase in the number of jellyfish. These article abstracts presented two different study designs: a series of longitudinal measurements and an experimental investigation, respectively. The video recordings include 15 students who worked in groups during one half-day activity that featured reading, discussing, and writing reports on the two article abstracts.

The digital tools

The Acid Ocean Virtual Lab and the carbon footprint calculator were developed within the I2I project by a team of researchers in marine science and in environmental education at the University of Gothenburg and Stanford University. The language used in the virtual lab and carbon footprint calculator is English. Therefore, all information, exercises, lab equipment, and calculations were in English. In order to explain the logic of the thesis, the digital tools used in the study are presented and described in some detail.

Acid Ocean Virtual Lab

In the Acid Ocean Virtual Lab, students have the opportunity to study ocean acidification. This is done by considering how the growth of marine organisms, in this case sea urchin larvae, is affected by lower pH-levels in the ocean as the result of CO_2 emissions. The virtual lab features three parts that the students attend to and use in the following order: Part 1) basic facts about ocean acidification are presented, Part 2) lab sessions are held, and Part 3) measurement exercises are carried out, and information about the consequences of ocean acidification are addressed through questioning. When entering the virtual lab, students are provided with some information about ocean acidification. The first part includes information, discussion questions, and exercises (see Figure 1). The introductory part ends by explaining how some living organisms are highly dependent on structures sensible to the water pH, which in turn leads to the hypothesis that a slight modification of pH in sea water might have a major impact on such marine organisms.

Figure 1: Screenshot of the information part in the Acid Ocean Virtual Lab.

In order to test this hypothesis, students reproduce an experiment that has been done recently in a marine research centre on sea urchin larvae growth. In the second part, the aim is to act as a scientist by experimenting in a virtual lab session. The lab session is designed to mimic a "real" lab environment with equipment such as beakers, pipettes, microscopes, etc. (see Figure 2). During the lab session, pop-up boxes provide students with information on scientific principles, such as the importance of sample size and number of replicates in empirical studies. While experimenting, students also answer pop-up questions that are directed towards the specific activity they are engaged in at the time. For example, if a student adds carbon dioxide to the water, the pop-up question could ask the student why he/she was doing so. In other words, these questions are designed to make students justify their actions and decisions, and to make them learn about consequences.

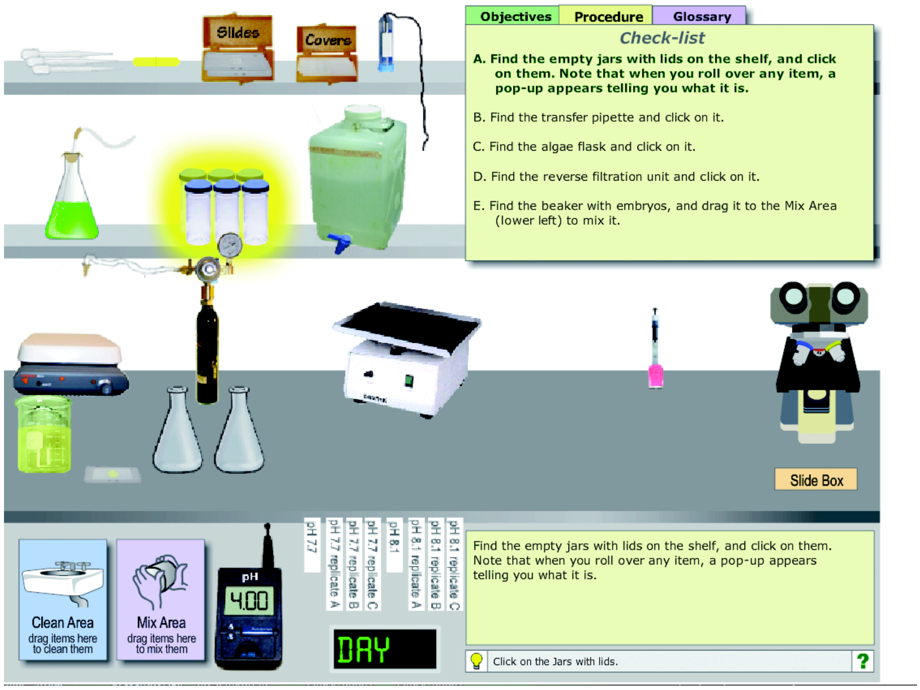

Figure 2: Screenshot of the laboratory environment in the Acid Ocean Virtual Lab.

In the virtual lab, students perform activities such as setting up replicate cultures, feeding the sea urchin larvae, making water changes, and observing the changes in the growth of the sea urchin larvae over time in waters at different pH levels. Every step in the laboratory work is clearly described, and the equipment students are required to use is highlighted (see the jars in Figure 2). The students set up replicate cultures in water with the regular pH level (8.1) and in water with a lower pH level (7.7).

In the third part, the students measure the growth of sea urchin larvae samples from both waters and compare them to each other. Via the use of a virtual ruler, the students measure the length of three larvae from water with the regular pH level and three larvae from water with a lower pH level. The findings from the experiment show how a drop in pH of 0.4 units affects the growth of sea urchin larvae. The experiments thus involve studying how the growth of the larvae is affected by the pH value. An added feature of the design of the virtual lab is that all the data produced by students are compared to authentic, relevant research data. Thus, the database of the virtual lab produced by the marine scientists enables the students to see how their results match those of the marine researchers. Finally this measuring exercise is followed by information on the consequences of a decreased pH level on ocean acidification.

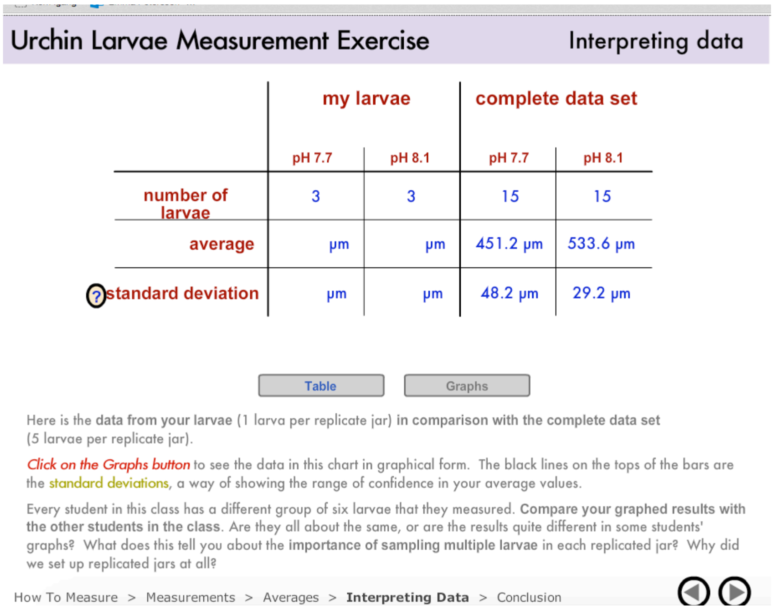

Figure 3: Screenshot of the measurement exercise in the Acid Ocean Virtual Lab.

The Acid Ocean Virtual Lab is a virtual tool operated by students through the available equipment; the computer mouse is used to click onto the lab equipment when interacting with it. For example, the students place their replicates under a microscope, use the CO_2 tank to change pH levels, drop algae cultures in the water using the pipette, and measure the growth of sea urchin larvae samples by using the virtual ruler. As mentioned earlier, a further important feature of the virtual lab is that when the students analyse and compare their findings, they do so based on the original and recent scientific data that have been incorporated into the lab.

Carbon footprint calculator

The carbon footprint calculator is a virtual tool that students use to calculate their personal carbon dioxide emissions and to perform a range of analytical activities. The students answer 50 questions by estimating their habits relating to a) transportation, b) home energy and appliances, c) food, and d) personal purchases (for an illustration of questions, see Figure 4). When the students start to use the calculator, they type in their name and select their country of residence. Following this, the virtual tool provides the students with information regarding the average carbon dioxide emission for the country chosen, calculated in kilograms per year. The students also answer whether they think their personal carbon footprint is likely to be lower, higher, or about the same as the average person in their country and in the world.

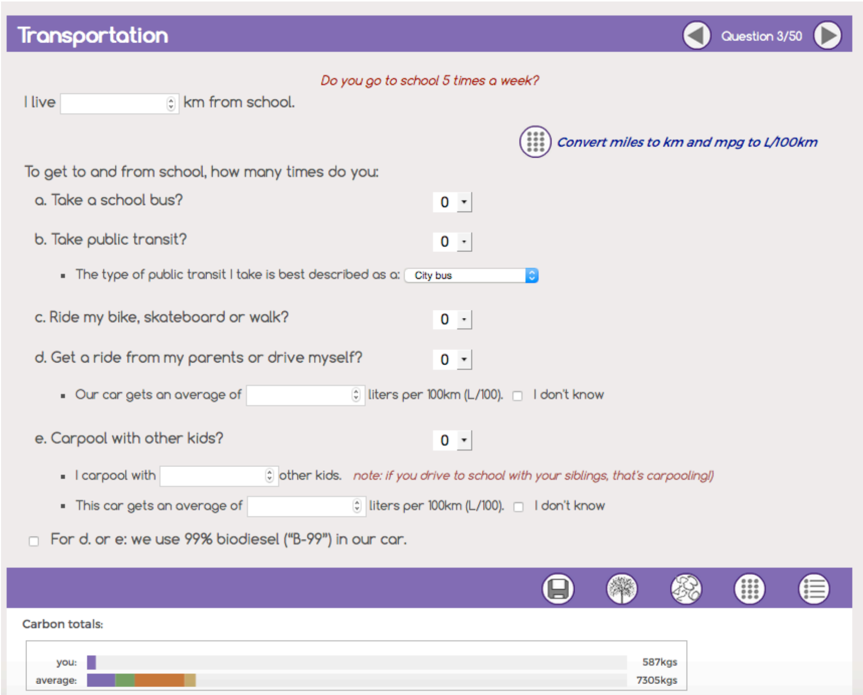

Figure 4: Screenshot of a question about transportation in the carbon footprint calculator.

The questions about transportation concern issues such as how students get to school, to their friends' homes, and to after-school activities. They are asked whether they travel by bike, bus, train, or car. The transportation questions also concern the estimated number of airplane flights they made or how extensively they used alternative ways of travelling (car, bus, or train) during the holidays in the past year. The area of home energy and appliances includes questions about energy use in domestic activities: for example, whether the students live in a house, an apartment, or a townhouse, and the number of people living together. In this context, issues of how the home is heated, the use of air conditioners or fans in the summer, shower habits, the use of washing machines and dishwashers, time spent in front of the TV and computer, etc. are raised. The majority of the questions (29 out of 50) refer to this category. Questions concerning the students' estimated habits in relation to food concern the amount of calories the students eat per day, if they are vegan, vegetarian, or non-vegetarian, if they eat organic food, how many times a week they eat take-away food, etc. The final questions are about the students' personal purchases. Examples of questions include whether the students choose tap water or water purchased in a shop, if they bring their own basket when shopping, how often they buy new electronics, if they recycle, etc.

Having answered all questions, the result of the students' personal carbon footprint appears and can be compared with the average carbon dioxide emission of the country chosen (see Figure 5).

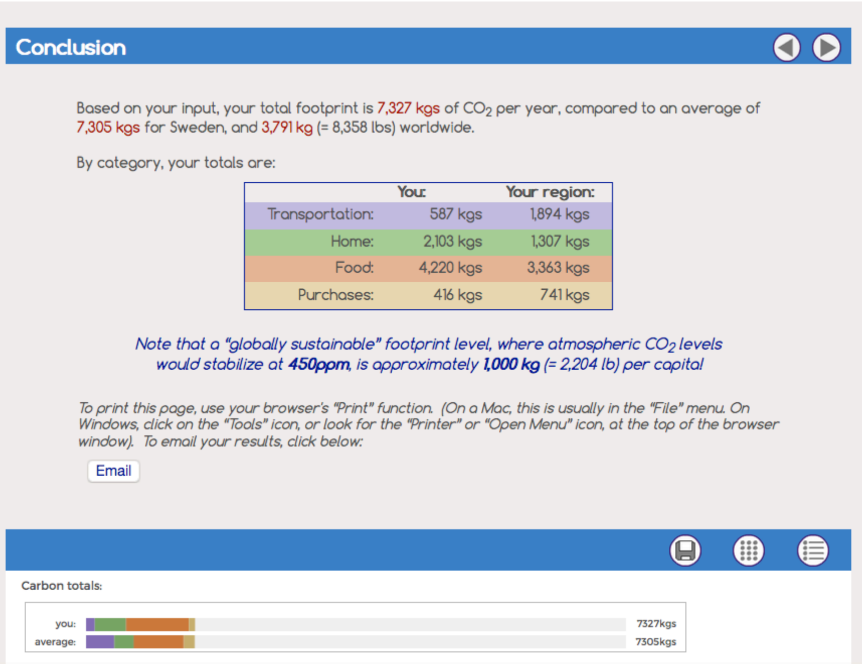

Figure 5: Screenshot of the comparison page of the carbon footprint calculator.

Their footprint is also shown as the students engage in answering the questions by means of an *average bar*, which allows the students to compare their values in relation to the average value of persons in the chosen country (see Figures 4 and 5). Thus, the value in the average bar changes in relation to what country the students select. For instance, the value of the average carbon footprint of Sweden differs from that of the United States. Again, the carbon footprint calculator is a tool that invites analyses by making explicit the environmental impact of students' activities.

When feeding information into the calculator and answering a question, the students get an immediate response that tells them how their actions impact the climate. Furthermore, the tool enables students to manipulate and to test their carbon footprint under different circumstances, that is, the students are able to go back and change their answers and see the consequences of alternative behaviours on their carbon footprint. For example, a student who answers that s/he makes two airplane flights in one year may modify the answer to say that s/he makes no airplane flights in order to immediately see the differences in the bar showing the total carbon footprint. This implies that the user can relate to climate change in new and more personalized ways, but also that the tool provides space for comparisons and analytical exercises in which the consequences of alternative choices may be made visible. Put differently, the calculator encourages an active consideration of how environmental impact changes in relation to different types of behaviours, a feature that is highly relevant for educational purposes.

To conclude, the virtual lab is a tool that allows students to engage with a world of organisms whose life conditions are affected by climate change and carbon dioxide emissions. The carbon footprint calculator, on the other hand, can be described as a calculating tool that offers students the possibilities to perform calculations connected to their lifestyle activities. In this sense, the virtual lab and the carbon footprint calculator are examples of two different mediating tools. However, both the virtual lab and the carbon footprint calculator are examples of tools that invite actions of testing and manipulating. Hence, activities that include the use of such tools enable learning activities that are different from those using traditional media, such as textbooks.

Research methods

This chapter presents the research methods used for analysing the questionnaire data and the video recordings collected. The chapter also deals with how ethical issues were handled.

Pre- and post-intervention survey

As described earlier, the students participating in the intervention survey were given pre- and post-tests with 17 questions about ocean acidification. Of the 511 students who participated in the pre-test, 469 completed the post-test. The instructional context of this was a curricular unit on issues relating to ocean acidification, in which the students had access to the Acid Ocean Virtual Lab. One of the questions posed was an open-ended problem solving task, which served as the focus for the analysis of Study 1. Consequently, the answers to the 16 multiple-choice questions were not analysed as a part of my research but were used by the I2I-project for evaluation purposes and to further develop design features of the Acid Ocean Virtual Lab. Compared to multiple-choice questions, open-ended questions imply possibilities for students to deliver an answer using their own words, and this better suited my research interests. Lemke (1990) argued that "only tests that require" students "to flexibly assemble words for themselves can indicate useful mastery of the language of the topic and its concepts" (p. 172). The open-ended problem was formulated in the following manner:

> You are an environmental scientist who is hired to complete an environmental impact report for a proposed project. Tropical Fisheries of Hawaii plans to open a fish hatchery on the Luau River, and the river opens to a bay with a large coral reef. Biologists are concerned that water discharge from the hatchery could impact the pH of the river in the bay. What sort of an experiment could you do to see if a change in pH might have an effect on the growth of the coral?

A sample of 80 students' answers to this question was selected to enable an in-depth analysis of students' responses. The sampling was random among the students who were present on both occasions. Students who took part in only one of the two tests were removed before sampling. Furthermore, in a limited number of cases, students gave very short answers that were obviously irrelevant to the task (e.g., "`hgfft`" or "…"), or answers in which the students replied to the question by referring to the virtual lab activity itself (e.g., "`The experiment we did in the online activity`") without commenting on the substance of the task. These students were removed and replaced with other participants through a random selection.[16] Four American teachers participated. The number of school classes and students taught by the four teachers varied, meaning that one teacher had several classes participating in the survey. Table 2 shows the data set that forms the basis of Study 1: the number of teachers, number of students, and the ages of students. Teacher 1 did not share any information about the age of the students.

Table 2: Participants in the pre- and post-intervention survey

	Teacher 1	Teacher 2	Teacher 3	Teacher 4
Samples selected	17	28	15	20
Number of students participating in the pre-test	106	181	178	46
Number of students participating in the post-test	105	175	138	51
Students' age	No information provided	12–14 years	14–16 years	17–18 years

Video recordings

The video documentation collected in the research project includes approximately 21 hours of recordings of a class of students in a Swedish upper secondary school. In the studies reported here, however, approximately 12 hours of video recordings were analysed.[17] Using video has several benefits. It is, for instance, possible to capture how activities are organized as they occur in their natural setting. In this respect, video "provides a

[16] The fact that the students respond to the question in this manner is per se a very interesting observation in the context of pre-and post-test designs. However, this issue is not within the focus of my research.

[17] The research project has collected additional videorecordings of the Swedish upper secondary class that participated in three studies in this thesis. These videorecordings contain a pilot study of the students during their work with the virtual lab and of students working on an assignment similar to the one in Study 4.

methodological resource with which to prioritize the participants' perspective" (Heath, 2010, p. 251). This implies that

> [r]ather than presuppose an overarching influence of the physical environment, we can use video to explore the ways in which participants constitute the occasioned sense and significance of features of the setting, such as objects, artefacts and the like. (Heath, Hindmarsh, & Luff, 2010, p. 87)

Furthermore, with video recordings, there is also the possibility of doing repeated analyses; the video films can be played over and over again in order to scrutinize what is going on in the activities recorded (Goodwin & Heritage, 1990; Heath et al., 2010; Jordan & Henderson, 1995). Additionally, video-recorded materials provide opportunities for having data sessions together with other researchers. For example, parts of my empirical material have been shown and discussed at different seminars and meetings, during which colleagues have contributed with valuable analytical inputs to my work.[18] However, it is important to mention that video recordings do not fully reflect what is going on within an activity, but

> always present the situation from a certain perspective, which usually reflects a particular research interest or a presupposition of what is important and what is not. (Lindwall, 2008, p. 61)

In order to capture as much of the activity as possible, one camera was used for each group. As mentioned in Chapter 5, the students in Studies 2 and 4 worked with one portable computer per group. For these materials, the cameras were positioned on tripods behind the students. In this way we were able to capture the computer screen as well as non-verbal activities (e.g., pointing to the screen and gestures to group members). Also, the programme ScreenFlow was used to record the students' activities on the computer screen. It was therefore possible to follow students' activities on the computer by observing both their non-verbal activities and their actions on the keyboard and with the computer mouse (for a screenshot of video data, see Figure 6).

[18] Parts of the videorecordings have been shown and discussed at Network for the Analysis of Interaction and Learning (NAIL), the University of Gothenburg Learning and Media Technology Studio (LETStudio), and at the Nordic Research Network on Learning Across Contexts (NordLAC).

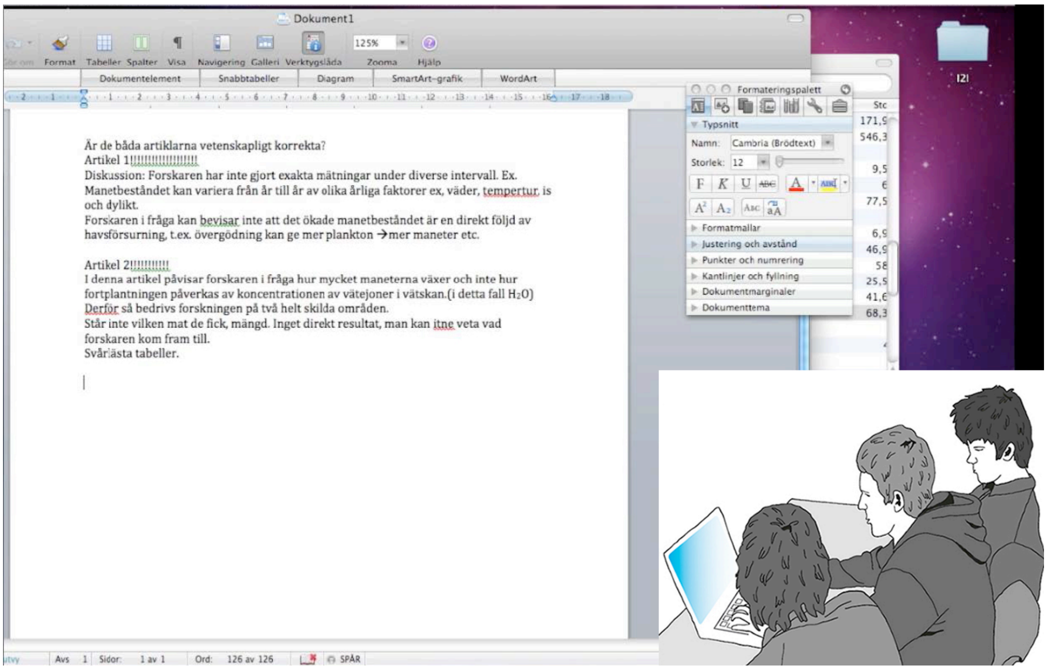

Figure 6: Illustration of the video data in which the video recordings of the students and the screen recording of the students' document have been synchronized into one film.

In the virtual lab activity, the teacher's introduction (approximately 20 minutes) was video recorded. The camera was positioned so as to capture the teacher and the whiteboard. Since the activity in the empirical material related to the use of a carbon footprint calculator did not require any computer use, we decided to position the cameras in front of the group of students. The decision about where to position the cameras, of course, has implications for what activities will be in focus in the analysis (cf. Åberg, 2015). For instance, in the empirical material concerning activities related to the carbon footprint calculator, one group of students returned to the calculator in order to manipulate and compare values. The decision to place the cameras in front of the students meant that the activities on the computer screen were not captured on film (for illustration of video data see Figure 7). Despite this, it was possible to analyse this particular activity (see Study 3, Excerpt 1). However, having recorded the computer screen would perhaps have brought other aspects into the analysis, for example how the students navigated in the calculator and how they manipulated values when answering different questions.

Figure 7: Illustration showing students' discussions after working with the carbon footprint calculator.

In all video recordings, one external microphone was placed near the students in each group in order to increase the quality of the audio recordings. When the teacher introduced the virtual lab activity (Study 2), he used a wireless microphone.

Generally, the students did not pay much attention to the video camera. On some occasions, the students turned to the camera and said something, but most often they ignored the camera. The students' personal conversations, as well as off-task discussions or activities on the computer, were not transcribed.

Analytic procedures

Pre- and post-intervention survey

To explore patterns in students' ways of developing their reasoning about how to outline an experiment after working with the virtual lab, the analysis focused on if, and how, there were signs that students had appropriated a scientific language and in what way they reasoned about how to organize an experiment (see Study 1). A Wilcoxon signed-rank test was carried out when comparing the pre- and post-test outcomes. Wilcoxon signed-rank test is a test for two related samples. By applying such a test, it is possible to compare two paired groups and to analyse the differences between them (Cohen, Manion, & Morrison, 2011). The test was carried out using the statistical software SPSS.

In examining how students appropriated a scientific language and reasoned about how to organize an experiment, the analysis focused on Lemke's (1990) concept of *talking science*. Lemke argued that "doing science is always guided and informed by talking science, to ourselves and with others" (p. xi). Talking science, in the case of this empirical material about outlining an experiment in writing, requires insights into a certain terminology with terms such as *sample*, *control group*, *observation*, and *comparison* (Lemke, 1990). In addition, and as Lemke emphasizes, mastering scientific discourse implies knowing how to combine terms and to express oneself in relevant manners. Accordingly, on the basis of findings of previous research in the area of science literacy, and considering the particular terminology used in the context of the virtual lab, a number of scientific concepts were selected in order to analyse signs of the students' appropriation of a specific corpus of concepts for the purpose of explaining the experiment they outlined. The scientific terms chosen are listed below:

pH
acid/basic/neutral
sample
test/measure/examine/observe
over time/before and after
control group
control
environment
compare

The terms selected were considered central in regards to the particular experiment included in the student assignment. The appearance of the chosen terms in the students' written answers before and after their interaction with the virtual lab was counted. One answer could include several of the different terms, and one term could be used more than once in an answer. The number of terms used in each of the students' answers in the pre- and post-test, respectively, was compared.

In order to analyse the students reasoning, an analysis was carried out that focused on the manner in which students were able to outline an experiment that would respond to the question given. All of the 80 selected students' answers to the open-ended question given in the pre- and post-test were analysed in detail. Patterns in students' ways of outlining an experiment emerged. For instance, some students suggested solutions to the problems with the water, while other students suggested different kinds of tests and so on. This analytical procedure resulted in an empirically derived five-level hierarchical outcome model that ranged from not demonstrating any understanding of how the issue raised could be addressed by means of an experiment to giving a functional account of how an experiment could answer the problem presented. The five-level hierarchical outcome model is further described in Chapter 7, in the summary of Study 1. When developing the category system, the students' answers were examined according to how explicitly, and with what degree of precision, their answers approached an account of an experiment that would be informative to illuminating the problem described.[19] In this way, the five-level category model is not a preformulated taxonomy but is empirically derived from the data.

Video recordings

Interaction analysis (Jordan & Henderson, 1995) is one of the methods used in the work of analysing video recordings in terms of the regularity of activities in the form of speech, non-verbal communication, and how people interact with artefacts and technology within a collaborative learning environment. Interaction analysis is based in ethnography (e.g., participant observation) and in other traditions that include those that give attention to the use of non-verbal resources in interaction, such as conversation analysis and ethnomethodology (e.g., Crook, 1994; Goodwin & Heritage, 1990; Sacks, Schegloff, & Jefferson, 1974; Stahl, Koschman, & Suthers, 2006). According to Raudaskoski (2006),

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[19] An example of a student response placed in Category 5, which included an answer that outlined an empirical study/experiment, is: "`You could grow some coral in a tank with water of the river's original pH, observe, and measure growth. Then coral could be grown in a tank containing water of an affected pH. The observations and measurements of both coral could be compared. Pieces of the different coral could also be observed under a microscope`". Answers that suggested different tests (e.g., "`Test the water they plan to use`" or "`Red litmus paper and blue litmus paper could be placed in samples of the water to test if it's acidic, basic, or neutral. Ph paper would then be used to test how acidic or basic the water is. If the water is either to acidic or basic it can be assumed that it is perhaps affecting the growth of coral.`") were placed in categories 3 and 4, respectively.

> interaction analysis offers a platform from which to research, also, those instances of human practice in which technology plays a crucial role. To be able to define what learning or change in practice could be, it is necessary, first, to find out how people actually interact through and with technology, and how they do that as embodied participants, not just language-using members. (p. 167)

In my empirical studies, the virtual lab and the carbon footprint calculator, as well as tools in text (article abstracts that exploit scientific language and resources, such as diagrams, tables, and equations) are regarded as significant artefacts in the students' ongoing learning activities. The video recordings make it possible to study details in interactions, and through studying the students' interactions, it is possible to understand what activities evolve when students engage in virtual lab work in environmental education, how they use a carbon footprint calculator as a resource for reasoning about actions in their everyday lifestyles, and how they articulate understanding in ways of critically examining scientific claims. It is important to acknowledge that the focus of my analysis has been to study signs of learning that appear in the material to which I have access. It has not been possible within this study to follow students over longer periods of time.

Furthermore, in interaction analysis, knowledge and action are seen as "fundamentally social in origin, organisation, and use, and are situated in particular social and material ecologies" (Jordan & Henderson, 1995, p. 41). This focus is consonant with the sociocultural perspective, where knowledge is seen as situated in interaction between participants and between participants and artefacts. To study students' collaborative work while engaged in assignments that concern research and environmental topics makes it possible to understand how the virtual lab and the carbon footprint calculator co-determine the pedagogical practice. Mercer (2008) viewed interaction as having both historical and dynamic aspects: "Historically, the interaction will be located within a particular institutional and cultural context. The dynamic aspect refers to the fact that conversations are not planned, they emerge." (p. 44). Thus, the potential of the digital tools needs to be studied in context.

Different analytical concepts were used to analyse the video recordings. As detailed in Chapter 4, Study 2 utilizes Latour's (1999) concept of *blackboxing* when analysing how students work with the virtual lab. In the empirical material concerning students' engagement with the carbon footprint calculator, the analysis focused on students' *accounts* (Furberg, 2009; Mäkitalo, 2003; Scott & Lyman, 1968) and on "accounting procedures" (Mäkitalo, 2003, p. 497) as they explained and justified their actions related to their everyday lifestyles, which became visible for them in the work performed with the calculator (Study 3). Similar to the analytic procedure in Study 1, the analysis in Study 4 focuses on Lemke's (1990) concept of *talking science* (see p. 70).

Transcriptions, representations and analytical steps

Using transcripts could be seen as a part of the analysis of the video observations. This method presents possibilities for studying the interaction in detail and enables the researcher to find patterns in the conversation or interaction observed (Rogers, Sharp, & Preece, 2011). According to Heath et al. (2010):

> Transcription is not simply a way of representing aspects of the activity, but provides an important resource in developing observations and getting to grips with the characteristics and organisation of the actions in which the participants engage. (p. 67)

The first step in analysing the video data involved watching the recordings and producing rough transcriptions of the students' interactions (verbal as well as actions related to the use of different resources, such as keyboard, computer mouse, and notes). The transcripts were read to identify different themes across the materials and examined with the aim of finding relevant instances of those themes and selecting them for further analysis. The next step in the process of analysis was to transcribe the selected instances in detail and to further examine the transcripts through repeated inspections of the video. Excerpts for publication were selected after considering how informative they were in illustrating the themes. In this way, the video recordings and the transcripts both were parts of the process of analysing the students' activities. Mondada (2007) argued that

> Transcripts and recordings are reflexively tied together in the production of their mutual intelligibility: transcripts facilitate access to the recordings and highlight detailed features for the analysis; reciprocally, recordings give to transcripts their evidence and substance, they allow and warrant an enriched and contextual interpretation of tiny conventional notations. They mutually produce their accountability, intelligibility and interpretability. (p. 810–811)

It was important to us that all activities surrounding the students' work with the various tasks and assignments were captured in the transcripts (Jordan &

Henderson, 1995). This was a process of carefully viewing the video recordings to study the verbal speech, the non-verbal behaviours, and the activities on the computer screen.

In the documentation of the students' work with the Acid Ocean Virtual Lab (Study 2), we were interested in scrutinizing the kinds of activities that evolve when the students engage in virtual lab work. Accordingly, we looked deeper into the material in which the students worked with all three parts part of the virtual lab: the introduction, the lab session, and the measurement exercises. A theme that emerged from the empirical observation as well as from reading the transcriptions concerned shifting patterns of engagement that emerged in the students' work. That is, in the material, it was identified that the students continuously shifted focus between the technology and its functions on the one hand and, on the other hand, the scientific content that they were expected to learn. The shift of focus then became the main theme that was demonstrated in three selected excerpts that distinctly show this in all three parts of the virtual lab.

In the empirical material that covers students' activities related to a carbon footprint calculator, the research questions concerned how the students used the values they received from the carbon footprint calculator as a resource for reasoning about their lifestyles and how they accounted for their footprints after using the calculator (see Study 3). A theme that was observed in this material was how the students made use of the output value received from the calculator as a means for their discussions. The students used the value to account for individual lifestyle activities, but they also related it to the average value of their country as well as to that of other countries. This theme was illustrated in three excerpts where interactions between the students and activities with other resources, such as the computer and notes, were transcribed.

In the empirical material where the students were to deconstruct scientific claims in two article abstracts, we were interested in how they were able to understand and to critically examine the claims made (see Study 4). We collaborated with the marine biologist who designed the student assignment and formulated aspects that could be questioned in both abstracts. The theme that emerged when analysing this empirical material was the manner in which the students questioned data-collection procedures, measurement procedures, and justifications of the conclusions. Five excerpts were chosen to illustrate how, in different ways, the students deconstructed the scientific claims made in the article abstracts.

The students' conversations were in Swedish. Therefore, all video recordings were transcribed in Swedish,[20] and the analyses were completed in the original language. The selected transcripts presented in Studies 2, 3, and 4 were then translated into English. The students described in the empirical material are aged 16–17 years. The transcripts have been translated into a colloquial, informal kind of English (cf. Lantz-Andersson, 2009a). The translation of spoken-language transcripts is a complex procedure. It is not only a matter of translating the students' words but also of considering social and cultural aspects. For instance, translating the students' conversations into formal English would have made them appear to be, as described by Bucholtz (2007), "stiff, and old-fashioned" (p. 801). This would suggest that the understanding of the transcripts would be different from transcripts approximating colloquial English. When interpreting the transcripts, the intention was to be as close as possible to the original formulations of the participants. Given the complexity involved in the translation of transcripts, the core analyses were performed based on viewings of the video recordings and the Swedish transcripts. An example of a translated transcript from Study 2 follows below:

[20] There are instances in the virtual lab activity (Study 2) in which the students read aloud in English. These instances are transcribed in English.

01.	Philip:	stir bar va e en stir bar (.) man kanske ska flytta den ((placerar muspekaren på co^2-tanken. Klickar på empty jars))
02.	Elias:	den ((pekar på skärmen))
		(paus)
03.	Tom:	stir bar e ju den som du hade precis
04.	Philip:	((drar med sig elektroden till stir plate)) den?
05.	Tom:	den som e i ja
06.	Philip:	de här går ju inte alls ju
		(paus)
07.	Philip:	((drar elektroden till stir plate)) va fan e en stir bar? ((tittar på Tom))
08.	Tom:	men de e ju den som e i FLASKAN
09.	Philip:	nä de e de inte alls de ((drar elektroden till stir plate))
10.	Tom:	jo de e de ju
11.	Elias:	nä de e en probe

01.	Philip:	stir bar what's a stir bar (.) maybe one should move that one ((places the mouse pointer on the co^2 tank. Clicks on the empty jars))
02.	Elias:	that one ((points at the screen))
		(pause)
03.	Tom:	stir bar is the one you just used
04.	Philip:	((pulls the electrode to the stir plate)) that one?
05.	Tom:	the one that's in it yeah
06.	Philip:	but this isn't working at all
		(pause)
07.	Philip:	((pulls the electrode to the stir plate)) what the hell's a stir bar? ((looks at Tom))
08.	Tom:	but it's the one that's in the FLASK
09.	Philip:	no it's not that one at all ((pulls the electrode to the stir plate))
10.	Tom:	sure it is
11.	Elias:	no that's a probe

Figure 8: Example of transcript from the virtual lab activity.

The method of transcribing was inspired by Jefferson's (1984) transcription conventions (see Appendix B), which are commonly used in conversation analysis and ethnomethodological studies.

Ethical considerations

Ethical questions have been taken into consideration throughout the research. We have followed the guidelines of the Swedish Research Council (Vetenskapsrådet, 2011). Participants were informed about the study and its goals. All students (from the United States and Sweden) received information about the I2I project, including the fact that it was a development project and that parts of it would be investigated. The Swedish students that were video recorded gave their written consent to participate beforehand. They all agreed to participate in the study. The students were informed that they could withdraw from participation in the study at any time. A small number of students chose not to participate in the groups being video recorded, and they were hence not filmed. However, these students participated in all activities in the same manner and together with the rest of the class but were placed in the classroom so that they were not captured on in the video recording.

The thesis project is a part of LinCS, and the data collection was supported by the LinCS-Lab. The video-recorded material is owned by the University of Gothenburg and is stored according to existing rules at the Department of Education, Communication and Learning.

Another consideration of the study was integrity; for example, student and teacher names have been changed and coded so as to maintain anonymity. Photographs or screenshots of students have been reproduced in the form of illustrated sketches or anonymized in other ways. The questionnaires were anonymized and marked with numbers so that it would be easier to choose the same students (numbers) in the pre- and post-tests.

7. Summary of the studies

As previously explained, the overall aim of the four studies was to examine students' use of digital tools and what implications such tools have for learning and reasoning about scientific knowledge and methods. The studies were set in the context of learning about environmental issues that specifically concern the nature and consequences of ocean acidification and carbon dioxide emissions. An overview of each of the four empirical studies is provided in this chapter.

Study 1: Exploring nature through virtual experimentation. Picking up concepts and modes of reasoning in regular classroom practices

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Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013). Exploring nature through virtual experimentation. Picking up concepts and modes of reasoning in regular classroom practices. *Nordic Journal of Digital Literacy, 3*(8), 139–156.

The background of this study is that virtual labs are currently made available for instructional purposes. Working with virtual labs is meant to provide opportunities for students to learn about specific scientific issues, but it is also recognized as a means to develop generalized skills about how to do experiments and how to evaluate the outcomes of such activities. Conducting experiments with such curricular ambitions is also in line with what Dewey (1938) referred to as engaging in *inquiry* in order to transform the problem encountered into something that we can grasp and act on. Learning about the logic of how experiments are conducted therefore qualifies as a significant constituent in the development of science literacy. In order to be able to reason scientifically, students need to understand the nature and implications of particular concepts and modes of reasoning (Lemke, 1990). Thus, in order to "talk science," students need to understand some of the specifics of the problem addressed (in our case, water quality) and how to set up a research study to answer the question formulated (cf., Ault & Dodick, 2010). The purpose of Study 1 was to investigate signs or indicators of learning by focusing on how students pick up concepts and modes of reasoning after having worked with a virtual lab (i.e., the Acid Ocean Virtual Lab). Exploring what students learn in terms of concepts or ways of reasoning involves examining the ways in which they express themselves when they talk and write and how they appropriate scientific concepts when formulating an answer that requires them to organize an experiment.

As described in Chapter 5, the virtual lab is a context for studying environmental issues, in particular ocean acidification and its consequences for marine organisms. This issue was explored through a virtual experiment on sea urchin larvae in water with different pH values that the students performed in the lab. Study 1 analyses American secondary school students' written answers to a specific problem concerning what kind of experiment they would suggest in order to study how a change of water quality could pose a danger to the growth of corals. The problem given to the students was formulated as follows:

> You are an environmental scientist who is hired to complete an environmental impact report for a proposed project. Tropical Fisheries of Hawaii plans to open a fish hatchery on the Luau River, and the river opens to a bay with a large coral reef. Biologists are concerned that water discharge from the hatchery could impact the pH of the river in the bay. What sort of an experiment could you do to see if a change in pH might have an effect on the growth of the coral?

The problem was given to more than 500 students in a written pre- and a post-study. Apart from this particular open-ended problem, all other questions in the pre- and post-test were multiple-choice. During the period of time between the two tests, the students worked with the virtual lab in their regular classes. The study included both quantitative and qualitative analyses of the students' written answers on the pre- and post-test. A sample of 80 students from the large data set was selected; as pointed out in the method section, in this case we have no documentation of the processes that evolved as students worked with the lab. In the analyses, the students' suggestions of how to design an experiment on the test prior to taking part in the virtual lab were compared to their answers after interacting with the Acid Ocean Virtual Lab. The analyses focused on how students appropriate (Vygotsky, 1978;

Wertsch, 1998) scientific terminology and modes of reasoning when responding to the problem of how to investigate water quality.

Two different types of analyses of the students' written responses on the two occasions were performed. The first type concerned the uses of scientific terms (e.g., sample, control group, and pH). The second level of analysis searched for patterns in the students' reasoning in terms of how close they came to suggesting an experiment (in the scientific sense) that would provide the information that was asked for. The results in relation to the first question show that the students used more scientific terms on the second occasion. The second analysis resulted in a description of students' responses in terms of a five-level category system derived from the data. The categories indicate a hierarchical outcome, which ranges from not understanding (or giving no answer) to answers that focus on attempting to gain information about the possible causality between water quality and the growth of corals, and that outlining an experiment that would be relevant (Category 5).

	Nature of the answer
Category 1.	Don't know/no answer
Category 2.	Suggests solution to the problem outlined in the task (with no indication of a study that could yield evidence/information)
Category 3.	Suggests testing the water (or pH or corals)
Category 4.	Suggests testing the effects of water on corals
Category 5.	Outlines study/experiment

The findings showed both stability and direction in the outcomes. The stability is obvious from the finding that 47.5 per cent of the students' answers are classified in the same category on both occasions. In 43.5 per cent of the cases, students are classified in a higher category on the post-test than on the pre-test (i.e., their answers increasingly invoked some kind of causality and/or outlined an experiment in the scientific sense). Consequently, considering that nearly half the students improved their reasoning skills in the post-test, this may be read as an indicator of students' learning some fundamentals about how to set up and describe an experiment.

An overall pattern in the students' pre- and post-test answers, however, was that rather few students specified the procedures of an informative and relevant experiment. Instead of proposing an experiment, the students most often approached the problem by suggesting a test, for example, a test of the water or the corals. Such answers imply that they focused on one parameter and that no proper experimental design was outlined.

Study 1 also demonstrated that the students answered different questions. A significant difference is whether they a) suggested a solution to the problem asked by outlining some kind of investigation/experiment (which is what was called for) or b) if they became engaged in analysing the problem of what would happen to the water if the fish hatchery was built. In the latter case, the students replied to the question from political or ethical perspectives (e.g., suggesting that the fish hatchery should move or close down), and they did not assume the perspective of how to organize a study that would provide relevant information. Thus, it may be concluded that the task of generating an answer to a problem by outlining an experiment is quite demanding compared to delivering a response by providing factual information. Furthermore, the results from Study 1 indicate that describing an experiment in writing is quite a demanding and difficult task for most students.

A conclusion of the study is that tools such as virtual labs may change the conditions for learning; however, their use does not necessarily mean that students will develop a general understanding of what is involved in designing an experiment. It is not enough to be able to perform experimentation and to know scientific concepts; one must also realize how experiments may address particular concerns and what the role of a scientific inquiry could be in decision making. Thus, being able to create a bridge between a problem and the experimental method most likely requires a sequence of experiences in which students encounter several examples of how such transformations of converting a problem into a relevant experiment take place. This is a discursive skill of thinking within a particular thematic pattern (Lemke, 1990), where one appropriates a skill of viewing the problem formulated as an object of research and not, for instance, as a general environmental problem. This observation is interesting since the very ability to understand what the question implies may be seen as a sign of science literacy. Building on this result, it is argued that it is not enough to add technology of this kind to enhance scientific reasoning; rather, it has to be embedded in a systematic pedagogical arrangement that focuses on specific educational goals.

Study 2: Virtual lab as context for learning—Continuities and contingencies in student activities

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Similar to what was the case in Study 1, this study involves the use of a virtual lab in environmental education activities. While the interest in Study 1 is on the product in terms of students' written answers to a problem solving question requiring them to outline an experiment, Study 2 focuses on activities in which students use the virtual lab in situ. The use of virtual labs in instruction is believed to provide opportunities for students to engage in inquiry-based learning, that is, learning about methods and procedures that correspond with methodologies practised by scientists (Bell, Urhahne, Schanze, & Ploetzner, 2010; Dewey, 1997). However, research on digital technologies in schooling has shown that the implementation of such technologies will not necessarily change established instructional patterns (e.g., Cuban, 1986, 2001). In Study 2, the aim is to investigate a virtual lab as a context for learning about ocean acidification. The following research question guided the study: What kinds of activities evolve when students engage in virtual lab work in environmental science?

The virtual lab used by the students is the Acid Ocean Virtual Lab. The students learned about ocean acidification and its effects on sea urchin larvae through a virtual experiment. As is mentioned in Chapter 5, the language used in the virtual lab is English, which implies that all text (information, exercises, instructions, names of lab equipment, etc.) is in English. A further important detail is that the virtual lab consists of three parts: 1) an introduction including basic facts about ocean acidification, 2) the lab sessions, and 3) measurement exercises and information about the consequences of ocean acidification.

In the present study, a class of 19 Swedish upper secondary students worked during one half-day activity with the lab. The students worked together in groups of three or four members. The teacher started the lesson by giving a short introduction on ocean acidification and its effects on marine organisms. After this introduction, the students worked in their groups with the virtual lab. Both the teacher's introduction and the students' group collaborations were video recorded and transcribed. In order to document the group work, the computer screens were also recorded to capture students' activities in the virtual lab.

The analysis was guided by interaction analysis (Jordan & Henderson, 1995) and grounded in a sociocultural perspective (Vygotsky, 1978; Wells, 1999; Wertsch, 1998), from which instruction and learning are viewed as mediated through the use of artefacts and as embedded in institutional traditions of communication. Furthermore, the notion of *blackboxing* (Latour, 1999) was used to conceptualize the conditions under which students operate in the virtual lab. As discussed earlier, blackboxing implies that in order to handle a tool efficiently, the user does not need to consider all the conceptual distinctions and technical features that are embedded in the tool (Latour, 1999). This means that virtual labs, as other tools of a similar kind, through their design, "blackbox" many features of their functionality. Study 2 explored what this suggests in relation to students' use of the virtual lab.

The findings from Study 2 illustrate the shifting patterns of engagement that evolve while students work with the virtual lab. The students continuously shift focus between a) engagement in relation to scientific content and b) engagement that is triggered by the features and functionalities of the tool itself. The first part of the virtual lab, which consists mainly of information, discussion questions, and exercises, generates few interactive elements (see Figure 1 on page 59). In this part, the teacher's introduction of the lesson guides the students in their discussions about the implications of ocean acidification on organisms and the environment. The re-use of one of the teachers' introductory explanations is illustrated through an excerpt in which a group of students remembers one of the teacher's examples from the introduction lesson and relates this to a question that needs to be answered in the virtual lab. The teacher's example of one of the consequences of changes in pH levels concerns how the clownfish in water with a lower pH level, when sensing the smell of a predatory animal, tends to swim towards the predator—and the danger—instead of away from it. The question for the students to answer concerned possible acidification impacts on marine organisms. Here, the findings illustrate how the students, while engaging with the virtual lab, are able to re-use the teacher's example regarding the effects of ocean acidification on clownfish when searching for an answer to the question they are addressing.

Another result that emerged from this study concerns the scaffolding function in the second part of the virtual lab, where every new step to take in the experiment is supported by a highlighting function of the equipment to use next (see Figure 2 on page 60). This design of the tool, which is intended to compensate for its blackboxed (Latour, 1999) nature, provides the students with a cue about how to move on in the virtual lab. The highlighting function, however, also involves tensions in the sense that the students do not need to make relevant distinctions when performing the virtual experiment but only need to differentiate whether an object is highlighted or not (cf. Linderoth, 2012). This is illustrated in the study by how one group of students struggles with what laboratory equipment to use in the experiment, which results in an activity of trying and testing all sorts of laboratory equipment over and over again until they finally find the correct one. When the students, for example, encounter difficulties in the lab environment in terms of not knowing what to do next in the experiment or what equipment to use, they tend to temporarily disregard the scientific content, and instead they redirect their activities into exploring features of the tool.

Furthermore, the findings show that also in the third part of the lab, including the measurement exercise, the students, to a considerable extent, focused on exploring the tool's functionalities. This type of engagement occurred, for instance, when a group of students encountered some software problems in the measuring exercise. In this part of the lab, the students measure the lengths of six sea urchin larvae by using a virtual ruler. After having measured five larvae, the students position the mouse pointer on the sixth larva but the larva does not appear on the computer screen. In continuing the measuring exercise, however, instead of measuring, the students iteratively enter numbers until the virtual lab indicates that their answer is correct. This way of guessing numbers illustrates the students' engagement as a trial-and-error activity. The example shows how the students in the measurement exercise shift focus in the activity. That is, when the students use the virtual ruler to measure the five sea urchin larvae, they engage in understanding the scientific content of measuring the outcome of the experiment. However, in the trial-and-error activity of dealing with the correct lengths of the sixth larvae by entering values, the focus instead is on testing the logic of the technology. From a pedagogical perspective, it is interesting to investigate these shifts of focus and what they mean for learning in complex virtual environments. What is demonstrated in the study is that the students' actions, when encountering difficulties in their virtual lab work, no longer necessarily are contingent on scientific content.

The findings of Study 2 illustrate that the tool co-determines the students' activities in significant ways. However, they also indicate that this does not always occur in the intended way, which points to the complexity of using virtual tools as parts of instruction. The virtual lab does not only contain complex blackboxed information and symbols but also offers students possibilities for performing sophisticated experiments that are well beyond their scientific background knowledge. This means that there are both processes and concepts incorporated into the virtual lab that need to be unpacked for the students to continue learning about acidification. In the study, it is argued that the environment itself cannot determine the educational value and relevance of such virtual settings. Rather, the relevance for learning is a consequence of the activities in which students engage. Virtual labs enable instructional support when it comes to understanding how to navigate in the environment and how to solve different tasks in order to proceed in the environment. However, the findings also illustrate gaps in the students' activities that present areas of opportunity for teacher guidance when learning. Thus, the virtual lab cannot be used as a stand-alone technology; the teacher has the important role of finding windows of instructional opportunity to support the students' practical work with virtual labs. A conclusion is that virtual lab work offers promising opportunities for inquiry learning, but instructional support is needed when it comes to unpacking processes as well as concepts and what they imply in relation to the underlying conception of ocean acidification.

Study 3: Making the invisible visible: How students make use of carbon footprint calculator in environmental education

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In Study 3, upper secondary students work with a digital tool which concerns environmental issues and climate change: a carbon footprint calculator. Carbon footprint calculators measure the environmental impact of our everyday lifestyle activities in kilograms or tons. As discussed previously, research regarding the use of carbon footprint calculators in instruction points to the advantages of employing such tools as a means of making students aware of the environmental impact of their activities and of realizing the more general problems of the carbon footprints of human activities (e.g., Hopkinson & James, 2010; McNichol et al., 2011). Thus, carbon footprint calculators are seen as tools for facilitating discussions about social complexities and sustainability that relate to scientific, economic, and ethical tensions (e.g., Cordero et al., 2008; Hopkinson & James, 2010; Kemppainen et al., 2007). The specific interest in Study 3 is how students make use of a carbon footprint calculator when reasoning about carbon dioxide emissions in relation to lifestyle choices. This is in line with the overall aim of the thesis of investigating how digital tools trigger students to reason about research and environmental topics that concern climate change. The study is guided by questions of how students use the carbon footprint calculator as a resource for reasoning and how they account for their footprints after having used it (Furberg, 2009; Mäkitalo, 2003, Scott & Lyman, 1968).

The study builds on video data from a half-day session with activities related to the use of a carbon footprint calculator. In the first part of the lesson, 15 students worked individually with the tool in order to calculate their carbon footprint. In the second part of the lesson, the students discussed their carbon footprint values in groups. As described in more detail in Chapter 5, the carbon footprint calculator includes questions about transportation, home energy, food, and purchases that the students should answer. When students answer a question by estimating lifestyle behaviours, they get an immediate response in terms of how many kilograms of carbon dioxide emissions the activity produces. Also, the students' carbon footprint values are related to the average footprint value of the country the students select.

The focus of the analysis is on the group discussions and on what modes of reasoning and arguing about the environment are made possible through the use of the calculator. The study investigates the students' accounts (Furberg, 2009; Mäkitalo, 2003, Scott & Lyman, 1968) in relation to how they discuss and compare their carbon footprints, that is, how the students in their discussions explain and justify actions in their everyday lifestyles.

Theoretically, the carbon footprint calculator is seen as a resource that mediates understanding (Vygotsky, 1978, 1997; Wertsch, 1998) of the consequences of students' lifestyle choices and activities, and from a further perspective, the understanding of more general and systemic features of emissions.

The results in Study 3 are illustrated through three excerpts that offer examples of how the students 1) account for average emissions of other countries, 2) account for travelling by plane, and 3) account for taking the car. In the first example, one group uses the carbon footprint calculator as a resource for reasoning about the average carbon footprint of the U.S. population. The students have a preconceived opinion of Americans as having a higher average carbon footprint than that of the Swedish population. In order to support this line of reasoning, the students decide to return to the calculator to study the average carbon footprint in the United States. The carbon footprint calculator shows that the average carbon footprint regarding transportation is high in the United States. Based on this output from the calculator, the students are triggered to reflect on why the United States has such a high value in this area. Their deliberations show how the students account for higher emission values by suggesting that the fuel prices in the United States are low, which is discussed as an explanation of why the carbon dioxide emission values are so high there. This is an example that illustrates how the calculator contributes to supporting analyses on a systemic level.

The second example shows that the students use the carbon footprint calculator as a resource to justify activities in their lifestyle by arguing that they have low emissions in other areas. For example, one group of students justifies going on vacation by plane by pointing to their overall low carbon footprint: Since they walk almost everywhere and never drive, the students argue that this compensates for an airplane flight. Hence, this reasoning (in a compensatory way) implies that the students in this example focus on their personal needs and preferences (travelling by airplane) instead of focusing on environmental issues from a global perspective, and they use what they see as their low footprint as something that entitles them to travel by plane.

The third example shows how the students use the carbon footprint calculator as a resource for analysing non-environmentally friendly actions in their everyday lifestyles. This is illustrated through an excerpt in which a student deliberates on his practice driving in an extended and detailed manner. The student discusses his activity of practice driving between two cities in analytical terms in order to explain the environmental consequences. In doing so, the students take different components into consideration (e.g., distance, model of the car, type of fuel, and costs of fuels). These components are incorporated into the calculator, and the outcomes are used by the student as resources for understanding the environmental impact of taking the car. To use this kind of tool in an instructional setting offers new possibilities for students to appropriate knowledge about crucial content, such as the relationships between everyday lifestyle actions and carbon footprint values.

The conclusion of Study 3 is that the carbon footprint calculator offers access points (Giddens, 2002; cf. Säljö, 2010) for the students to a) make comparisons between their carbon footprint results and the average emission values of their country and between their country and those of other countries, b) to justify their own less environmentally friendly lifestyle choices by invoking accounts that explain that they have a low footprint value in other areas, and c) to quantify, analyse, and discuss pros and cons in relation to their emissions values. This means that the incorporated conceptual distinctions and operations in the tool become accessible to the students without full mastery of their original scientific form (Vygotsky, 1997). Consequently, as argued in the study, the tools are loaded with conceptual constructions that are beyond the students' comprehension. However, when students make use of these tools in a context where environmental topics are on the agenda, the output value becomes a resource for their reasoning about the environmental impact of various activities. For example, they are able to reflect on the carbon footprint result and on actions they could take to improve it. One way in which the students account for their carbon footprint is through relating their received value (amount of carbon dioxide emissions) to the average values of the country that they have selected. The students use this average value as an indicator of whether or not their own actions are environmentally friendly. However, the students do not comment on whether or not the average value of, for instance, Sweden is environmentally sustainable or what it means in terms of sustainability on a global level. Similar to the arguments on virtual labs in instruction in Study 2, the findings from this study illustrate that in terms of the use of such tools in instructional contexts, certain representations need to be unpacked in order for the students to be able to understand their footprints related to a more general level.

The study shows that in working with a carbon footprint calculator, the students make experiences that are relevant for their environmental awareness, and that they, in fact, connect to how they live their lives. By supporting such observations and comparisons, the carbon footprint calculator underpins the students' reasoning about their own impact in ways that otherwise would not be possible. The calculator allows for quantification of something that is abstract, that is, it contributes to making the invisible visible by presenting the consequences of their choices on the environment in concrete figures. This mediating potential is also of interest for their understanding of how the environment may be studied in a scientific manner and is a step towards being able to reason about the sustainability of activities on a systems level.

Study 4: Deciphering the anatomy of scientific argumentation: The emergence of science literacy

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Similar to Studies 1 and 2, this book chapter builds on an interest in students' learning through inquiry (Dewey, 1938). The difference between the present chapter and Studies 1 and 2 is that the students do not engage in inquiry per se. Rather, the students' assignment in Study 4 is to understand scientific argumentation through scrutinizing inquiry procedures and claims presented in two article abstracts on ocean acidification that were written by researchers on the I2I-team. More specifically, the research reported in the chapter concerns to what extent the students are able to realize the logic and validity of scientific procedures and claims in the context of climate change. The students' assignment included reading two article abstracts and answering questions requiring them to take a stand on the trustworthiness of the scientific claims presented in both abstracts. The problems addressed in the article abstracts involve the correlations between an increasing number of jellyfish in the ocean and a change of pH conditions following ocean acidification. The authors of the two abstracts approach this environmental problem in two different ways. The first abstract presents a series of longitudinal measurements of the prevalence of jellyfish. The claim in this study is that ocean acidification is responsible for the increase in the numbers of jellyfish in the ocean and that the longitudinal study proves this. The second abstract, as an alternative, introduces an experimental investigation in which the aim is to test the conclusion made in the first abstract. The experiment implies that jellyfish were collected for the experiment. Half the jellyfish were kept in controlled pH conditions (8.1), and the other half were kept under low pH conditions (7.7) for a period of two weeks.

The empirical material in Study 4 consists of video documentation of the students' discussions and negotiations of how to formulate answers to the questions posed in the assignment. The questions concern whether the two article abstracts are scientifically accurate, and if the conclusions in the abstracts are justified. The screen was also captured in the video recordings to enable us to follow how the students' worked with formulating their answers (i.e., their actions on the keyboard). All in all, this study provides a detailed analysis of five excerpts demonstrating how 15 upper secondary students, together in pairs or in groups, read, discussed, and wrote reports on the article abstracts. Theoretically, the article abstracts with which the students' worked are understood as rich cultural resources (Säljö, 2011; Vygotsky, 1978; Wertsch, 1998), including scientific language and other resources, such as diagrams, tables, and equations, for use in reporting findings and in making claims. Lemke's (1990) concept of *talking science* is used as an analytic concept in the investigation of how students reason and argue about the validity of scientific claims, that is, how they develop science literacy (Lundqvist, Säljö, & Östman, 2013).

The five excerpts illustrate how the students deconstruct scientific claims through questioning a) procedures of data collection and data quality, b) procedures of measurements, and c) the justification of the conclusions. The results show that the students deconstruct scientific claims in different ways. One such way is that the students identify problems with the design of the investigations in the article abstracts without further elaboration. Examples of such instances include students questioning the duration of the studies and the quantity of jellyfish used in the studies. For example, one group of students questions the procedures of data collection and data quality in the first article abstract. Here, a student stresses that the number of jellyfish in the two conditions (control pH vs. low pH) is too small. In doing so, the student suggests that the experiment should include more jellyfish to be reliable. This is a correct observation, since the results from an experiment whose sample size is too small could be misleading due to a low power and low resolution of data. Even though the students do not engage in any further elaboration on the low number of jellyfish in relation to the claims made in the article abstract, they do show an understanding regarding the meaning of sample size. In this chapter, it is argued that this way of deconstructing scientific claims without further elaboration could be understood in several ways. One way to understand why they did not engage in further explanations could be that they regarded the issue as being incorrect in an obvious manner and therefore did not consider it necessary to discuss further. Another reason reflected on in the chapter is that the students find it difficult to formulate the underlying causes of the identified problem. These are skills that students need to practise and learn through extended inquiry-based activities. Thus, this result points to the complexity of learning the logic of inquiry and developing science literacy. A third reason as to why students question scientific claims without further elaborations, also identified in the chapter, is that making such claims explicit is not something that people necessarily do in their everyday lives. However, in both institutional learning practices and in research, one of the ground rules for communication is to support and to justify claims (Edwards & Mercer, 1987). In Study 4, this similarity between institutional learning practices and research focusing on communicative practices is discussed. Making the link between claims and their justifications in text as well as in talk is a hallmark of both research and argumentation in school learning. This is a link that could be much more emphasized in the contexts of learning science and scientific inquiry.

The findings also shed light on how students in their deconstruction of scientific claims formulate their critique by questioning data collection, by asking questions, expressing doubt, and by suggesting alternative views and explanations. In doing so, the students use marine biology terms and knowledge to support their line of reasoning. The students, for example, question whether variables other than ocean acidification (e.g., fluctuations and variations in the ocean) could have consequences for the increasing number of jellyfish. This is not taken into consideration in the two article abstracts, and the students' attention to such details is an indication of how they are on their way to appropriate a scientific mode of reasoning about the problem. In Study 4, it is argued that to understand what variables to take into consideration when designing an experiment also requires understanding specific domains of knowledge that are relevant for the investigation. Here, the students show skills in thinking within particular thematic patterns (Lemke, 1990), where they appropriate a mode of reasoning which targets the problem with an increasing number of jellyfish due to ocean acidification.

To sum up, to decipher the anatomy of scientific argumentation requires understanding some of the elements of scientific inquiry. What is observed in this study is how students have taken some steps towards learning to "talk science." To be able to scrutinize research studies more in depth, the students would need further exposure to the procedures and conceptual resources used to observe and to codify the world in scientifically relevant manners.

8. Discussion

The four studies described in this thesis aimed at investigating tool-mediated activities in the context of environmental education. Underpinned by a sociocultural perspective on learning, the studies explored how a virtual lab and a carbon footprint calculator 1) co-determine activities and students' reasoning about scientific knowledge and environmental topics and 2) what implications the use of such tools have for the development of science literacy.

The combined results of Studies 1, 2, and 3 show that digital tools offer possibilities for students to perform relevant experiments and to learn about complex relationships between human activities and carbon dioxide emissions. However, the results also point to dilemmas connected to using such blackboxed (Latour, 1999) tools in instructional settings. On the one hand, the students are able to easily access sophisticated, complex scientific knowledge and engage with it in productive ways. On the other hand, in order to make meaning in manners that are relevant to understanding scientific argumentation, some of the blackboxed knowledge needs to be unpacked. In this sense, my results are yet another illustration of the fact that such digital tools are not self-instructive. Scaffolding is needed by competent partners, such as a teacher, in order for students to understand processes and concepts that are incorporated into the tools.

Studies 1, 2, and 4 demonstrate that inquiry-based activities, that is, activities that require students to develop an understanding of the logic of scientific methods (e.g., of experimentation) also need to be practised repeatedly. Students should be offered many possibilities to encounter and to work with inquiry-based activities in order to be able to appropriate the fundamentals of experimentation as a mode of generating knowledge about a problem. To realize what conceptually counts as an experiment in the scientific sense implies appropriating a concept that is quite powerful and that, in the Vygotskian sense, is a typical scientific concept. In this case, and as Gyllenpalm (2010) pointed out, the problem is also that the scientific meaning of the term *experiment* has to be distinguished from the more everyday uses of this term (where any manipulation may be seen as an experiment). The students in the research presented here seem to come some way towards understanding what qualifies an experiment, but there are rather few, for instance in Study 1, who explicitly use a scientifically precise concept to structure their responses to how a specific experiment could be organized.

These general findings are discussed and elaborated on in this chapter in three separate parts, which focus on a) digital tools as access points to scientific understanding, b) instruction in digital environments, and c) the development of science literacy.

Digital technologies in instruction: Access points to scientific understanding

A central argument of the three studies in which the students' activities are related to the virtual lab and the carbon footprint calculator (Studies 1, 2, and 3) is that these specific digital tools enable activities that cannot be organized without them. The experiment that the students performed in the virtual lab would be difficult to organize in a traditional school lab, since, for instance, this particular experiment requires students to follow climate effects over long time spans and to use statistical data from authentic research. When it comes to the activities of using the carbon footprint calculator, the conceptual knowledge mediated by this tool is quite multifaceted, and the calculations involved are also complicated and would have been much too complex to carry out without the tool. In this way, these tools have the potential of offering students arenas for learning and reasoning about research and environmental topics that concern climate change which go beyond what a traditional school lab exercise could offer.

The research reported in this thesis found that such digital resources imply possibilities for students to engage in meaningful and quite abstract discussions without extensive background knowledge. A significant finding of this research is thus that these tools offer access points to observations and analyses of scientific knowledge and climate change that enable the students to draw meaningful conclusions. As argued in Study 3, "conceptual constructions that are integrated into the carbon footprint calculator provide 'short-cuts' for the students' reasoning" (Edstrand, 2015, p. 19). Thus, the tool provides the students with values that become productive starting points for their analyses and discussions. The study illustrates how the students explore and analyse their calculated carbon footprints but also how they use the calculator for making national and international comparisons of countries' average footprint values. For example, in the study, one group of students returned to the calculator to discover how the average national carbon footprints of the United States are produced. In this sense, information regarding estimated carbon dioxide emissions that are caused by the habits of Americans with respect to food, transportation, home energy, and appliances are easily accessible and may be subjected to comparisons and analyses. The interface of the carbon footprint calculator is easy for the students to make sense of and to manipulate when navigating back and forth, alternating between different countries, making comparisons, etc. These manipulations result in questions that in turn generate discussions about potential reasons for the national footprints. For instance, why does the U.S. average carbon footprint show high emission values in the transportation section? In this sense, the tool, despite the individual emphasis of the design, supports analyses that concern societal issues that go beyond measuring the personal footprint that may lead to discussions and deliberations on a systems level.

For tools to serve as shortcuts to scientific knowledge and reasoning, various built-in design characteristics are of importance. An interesting design feature of the virtual lab is that the students are able to compare their results with results from statistical data from authentic research. To compare with or to use already collected data also reflects what currently happens in scientific work, where an increasing number of analyses are done through operating on material gathered from big data bases. Put differently, today's research studies in many fields are carried out by means of big data that are available in the data bases of research centres or in the statistical offices of nations and organizations (e.g., Belsky, Hellenbrandt, Karen, & Luksch, 2001; Hine, 2006; Lenzen, Moran, Kanemoto, & Geschke, 2013). Accordingly, the students' work in the virtual lab is not so different from how many scientists work and will work in the future. Consequently, in addition to the advantages of being cost-effective, time-efficient, safe, etc. (Bose, 2013; Bhargava et al., 2006; Darrah et al., 2014; Shim et al., 2003; van Joolingen et al., 2007; Zacharia, 2008), the utilization of data bases, in many respects, makes the activities in the virtual labs come closer to scholarly work than does traditional school work. Reflecting these developments, the type of resource that the virtual lab represents will most probably be an even more frequent element of both schooling and scientific research in the future.

Carbon footprint calculators and virtual labs are examples of tools that contain data which are generated in real settings, for example concrete values indicating the personal environmental impact or authentic research results on specific topics. In this way, findings and outputs emerging from working with digital tools represent something more than practising only in the context of exercises produced for performing a school task. This is an interesting feature of the combination of data bases and digital tools that may contribute to making the tasks performed more relevant, in the sense that it is possible to produce insights that comment on what is happening to the environment.

Digital technologies of the kinds used by the students in my studies thus offer powerful and varied access points to scientific understanding. There are, however, also dilemmas involved when using such tools in instructional settings. These dilemmas are, as mentioned before, connected to the blackboxed nature of the tools, where much knowledge and many conceptual premises are hidden. As pointed out in Study 3, the average bar that illustrates the carbon footprint of a typical person in the country that the students have selected (Sweden) is used as a justifying resource for interpreting whether or not specific actions are environmentally friendly. Thus, there are several aspects of such a tool as the average bar that need to be unpacked as the outcomes are used as resources for discussions and analyses. On a technical level, there is at present no uniform definition of the selection of gases and levels included in the measurements of carbon footprints. This means that the user needs to understand that such environmental impact calculations are complex and contain uncertainties and approximations (cf. Pandey et al., 2010). Since the basis of the approximations involved in the design of the tools in themselves are based on socioscientific, contested, and ongoing discussions, this could be an interesting kind of issue to highlight as a part of instructional activities. For example, the discussions on the footprint values received by consuming meat in comparison to vegetarian food (e.g., Tom, Fischbeck, & Hendrickson, 2016).

Another issue related to an inherent feature of the average bar is what that value represents from a wider perspective. The carbon footprint of an average person in Sweden is 7,305 kilograms of carbon dioxide emissions per year. The globally sustainable footprint has a value of approximately 1,000 kilograms per year, which implies that the average footprint of Sweden is nowhere near a sustainable value. From a pedagogical perspective, this is a relevant issue to unpack, since the Swedish average carbon footprint seems to invite the students in Study 3 to reason in compensatory ways. For instance, one group of students discusses airplane flights and argues that an overall low carbon footprint could compensate for travelling by air. This is again both an interesting and relevant argument indicating that discussions of socioscientific issues need to be carried out on multiple levels (Dawson, 2015; Sadler et al., 2007; Sadler & Donnelly, 2006; Sadler & Zeidler, 2005, Åberg, 2015). To meet the international agreements regarding the guidelines for environmental education (UNESCO, 2004), where there is an emphasis on the relationships between individual and collective actions, it is necessary to understand behaviours and actions as a part of a system (Fauville et al., 2016; Sinatra et al., 2011; Sterman, 1994). Hence, on the one side, to see the personal carbon footprint on a systems level implies that it is problematic to argue that an overall low carbon footprint can compensate for flying when the average already may be too high. On the other side, the students' reasoning could be seen as an initial step of understanding the connections between personal actions and their effects on the environment in the form of carbon dioxide emissions related to the world at large. Thus, it may be seen as an initial step in a learning trajectory, which will reach a systems level with proper support and scaffolding.

An additional dilemma connected to the design of the tools enabling shortcuts both to scientific and procedural knowledge is that the students sometimes reproduce concepts without mastering them. This is, for instance, illustrated in my empirical material through instances in the students' virtual lab work, in which they struggle with the names and functions of the lab equipment they are using. When students encounter difficulties while working with digital tools, they tend to leave the content and instead orient their actions towards exploring functionalities of the tool (cf. Lantz-Andersson, 2009b; Petersson, Lantz-Andersson, & Säljö, 2014). The highlighting function in the virtual lab exemplifies such a feature of the tool, where the students' actions are not contingent on scientific substance. When the students practise a virtual experiment in the lab session, the equipment they are to use in the next step is highlighted. As I have pointed out, this type of guiding resource, designed to scaffold the work, however also invites the students to click on the lab equipment features without considering what functions they have in an experiment or their role in knowledge-seeking practices (cf. Manlove et al., 2006). This design feature points to an important tension. Through its design features, the tool at one level supports the students in their laboratory work. At another level, however, the support functions also trigger the students to speed up and to focus on how to *proceed* in the lab environment, sometimes at the expense of their understanding of the concerns involved. Consequently, this attention to functionalities of the tool may overshadow the attention to the underlying scientific processes involved in an experiment; again, this points to the tensions involved in using blackboxed tools.

The ecology of instruction in complex and rich digital environments

In my research, I have, in a number of ways, presented how digital tools in instructional settings provide new learning activities and experiences and that they in this sense co-determine the conditions for learning in novel ways. The role of digital technologies in environmental science learning is, as already emphasized, dependent on features of the instructional situation of which they form a part (Lave & Wenger, 1991; Säljö, 2005) and on what activities people develop when engaged in such tool-mediated learning activities. The results from my research demonstrate that digital tools contribute to learning but at the same time the students need to understand complex knowledge, for instance what an experiment is and what information one will gain by conducting experiments.

In Study 2, the importance of the teachers' interaction with the students was apparent when studying how the students reasoned about ocean acidification while working with the virtual lab. Here, the students re-used the teacher's formulations from the introductory lecture about ocean acidification. Worth noting is how the teacher, through his pedagogical approach, structured the content related to ocean acidification, which is what the students will practise within the virtual lab in the second part of the lesson. By designing the lesson in this manner, the teacher anticipated what kinds of concepts, definitions, and examples related to aspects of ocean acidification that the students will need in order to make meaning of the virtual lab activity. In this way, the teacher, in an anticipatory manner, unpacked the concept of ocean acidification by giving concrete examples of how certain organisms and fish change their behaviours due to decreasing pH levels. Video-recorded sequences of the students' work with the virtual lab show how they pick up aspects of the introduction and appropriate elements of the teacher's reasoning and make them "their own," as Wertsch (1998) put it. This is a clear illustration of how teacher contributions metaphorically function as "glue" (Strømme & Furberg, 2015) while supporting the students in their attempts to understand the rather complicated chemical, biological, and other processes involved in ocean acidification and what they mean for the organisms as well as for the whole eco system. This result illustrates how the virtual lab is a part of a web of meaning-making in which teacher inputs, student work, and features of the tool itself jointly co-determine the outcome.

It is important to acknowledge the conceptual premises inherent in digital tools. In the carbon footprint calculator, there is a concept of “footprint” which seems to quickly become a living and understandable tool for these students but which per se is a rather new innovation. It is interesting to see how this concept is put into use without any obvious difficulties, not only by the students in my study but also in the public discourse on sustainability. This illustrates how a “scientific concept,” in Vygotsky’s sense, sometimes may become a part of everyday language. Carbon footprint calculators have been developed on the basis of the idea that human lifestyle activities can be made tangible as leaving “footprints,” in the form of carbon dioxide emissions calculated in kilograms per year. This concept may be regarded as a rather new cultural tool that enables discussions about human-driven climate change that would not have been possible a couple of years ago. In accordance with earlier studies (Cordero et al., 2008; Fauville et al., 2016; Hopkinson & James, 2010; Kemppainen et al., 2007; McNichol et al., 2011), the present research demonstrates that a tool such as a carbon footprint calculator becomes a structuring resource for students in their understanding of the concept of carbon footprint, at least on an individual level. This is, for example, illustrated in the empirical material through a discussion in which one student accounts for the action of taking the car by structuring his reasoning around parameters such as model of the car, type of fuel, how much fuel the car uses, distance travelled, and number of persons in the car. These distinctions are conceptually integrated in the transportation section in the calculator. In this way, through having used the tool to calculate the environmental consequences of his own driving, the student develops new cognitive habits (Dewey, 2005), that is, new ways of reasoning about these environmental issues. As Dewey put it:

> Habit means that an individual undergoes a modification through an experience, which modification forms a predisposition to easier and more effective action in a like direction in the future. (p. 197)

Accordingly, the activity of using the calculator makes it possible for the students to understand what distinctions that are relevant in a discussion concerning footprints linked to how they transport themselves. However, it is important to keep in mind that developing an understanding about the relationships between everyday activities and carbon footprint values does not automatically imply that the students actually transfer such knowledge into action. Since the aim of the carbon footprint calculator is to visualize the individual's lifestyle by showing the amount of carbon dioxide emissions that emerges from the person's choices and actions, it is not surprising that the general focus of the students' discussions stays at an individual level. In our material, they only occasionally invoke issues that relate to a systems level. When learning further, students have to be made aware of how these issues appear on the systems level. They have to realize, for instance, that there may be structural features of the environment which support sustainable choice, or, alternatively, make such choices more difficult. If we return to the student who accounted for taking the car, there might be systemic elements of the situation, such as distances involved, access to public transport, etc., that play a decisive role but which the individual has no immediate possibility to influence. So, even if people would want to use the bike or public transport, this might not be possible due to the state of, for example, the infrastructure. Jensen and Schnack (2006) highlighted the limitations of focusing only on the individual level:

> If actions that are set up only deal with the individual or school level (as in building a compost heap only for the use of the school or turning out the lights on leaving the classroom) we run the risk of teaching pupils a simplistic and individualistic approach to environmental problems and their causes. (p. 480)

Consequently, the systems level needs to be a central part when dealing with these issues in environmental education. Even if digital technologies make it possible for the students to engage in complex and rich operations that otherwise would not have been possible, it is clear that in this case there is a need for support in order to understand consequences and patterns on a systems level. Thus, irrespective of the refined tools, a systematic pedagogical framing in the classroom will be necessary for students to reach a level of knowledge that will enable them to analyse and argue about systemic causes and consequences. However, the tool and its benefits may be seen as triggers that provide support for such a learning trajectory.

Developing science literacy

Learning about socioscientific issues in environmental science education requires students to adopt a critical approach to claims and arguments presented by people from different disciplines. In the discussion about students' understandings of scientific knowledge and environmental topics, it is worth reiterating the complexity of this kind of knowledge. What makes this subject complex is not only its socioscientific character, but also the idea that knowledge and concepts related to environmental education are contested, implying that not even researchers agree on all aspects included. Both in the national and international arenas, several different concepts and definitions are now used when referring to environmental topics. For instance, UNESCO uses terms such as *environmental education*, *education for sustainable development*, and *climate change education*. In a cross-national report (Blum et al., 2013), researchers from Denmark, Singapore, Canada, and the United Kingdom point to the conceptual challenges involved in the usage of these terms through examples from each of the participating countries. In the report it is concluded that

> a diversity of understandings of ESD [education for sustainable development] and its related terms (including EE [environmental education] and CCE [climate change education]) have developed – and continue to develop – worldwide. The situation is further complicated by the fact that multiple meanings coexist in many countries, used simultaneously by various individuals and organisations at a range of governmental and geographic scales. (p. 208)

In addition, different countries have different political and economic interests when it comes to environmental issues, and this, naturally, will have consequences for the prevailing discourse on what kind of changes that are discussed in the effort to make the world more environmentally sustainable. An added complexity in teaching and learning about environmental topics concerns central concepts such as climate change, the greenhouse effect, and global warming. These concepts are controversial in the sense that they are used differently in different contexts (Säljö et al., 2011). For instance, students often understand the greenhouse effect as an environmental problem (e.g., Andersson & Wallin, 2000; Shepardson, Niyogi, Choi, & Charusombat, 2009). This interpretation of the concept is usually in line with how it is presented in the media. However, as Jakobsson and colleagues (2009) stressed, students often fail to understand that there is a natural greenhouse effect which is essential for life on earth and that there is also an anthropogenic effect, which is "caused by human combustion of fossil fuel" (p. 980). Thus, the thematic ingredients of environmental education contain both controversies (e.g., political and economic) and conceptual and terminological ambiguities. Being aware of these kinds of ambiguities and uncertainties is a matter of science or scientific literacy in the sense that students, and people in general, have to understand that the conceptualizations vary and that different definitions are used in different contexts and by different actors.

A focus of my research was on how students in problem solving activities develop an understanding of science and scientific methods. As was argued earlier, realizing what an experiment is and how it is organized is an example of such insight into science approaches to knowledge-building. The students have to be familiar with the decisive steps of an investigation if it is to be counted as an experiment; they have to know how the results are discussed and evaluated, and they have to be clear about what claims can be made on the basis of a report. Understanding experimentation as this kind of problem solving practice founded on scientific procedures is, in Dewey's (1938) argumentation, an essential component of inquiry. To appropriate the principles for how inquiry is carried out when investigating a problem is, however, not achieved overnight; rather, it needs to be practised repeatedly over time (Bybee, 2000; Gyllenpalm, 2010; Hart et al., 2000; Lager-Nyqvist et al., 2011). The Swedish students who participated in Studies 2, 3, and 4 were exposed to many inquiry-based activities during one school year. The empirical material that forms the basis for Study 4 was collected at the end of the school year, and the students, among other activities, had worked with the virtual lab and the carbon footprint calculator, had visited a marine station, and had written various assignments and reports aimed at triggering them to document and to reason about research and environmental topics. The ways in which the students in this study managed to deconstruct scientific claims and reasoning and to realize whether they were valid or not illustrate that they understand some of the procedures of how to evaluate results from research and the validity of the claims made. In their reasoning, the students invoked domain-specific knowledge by using marine biology terms that they appropriated through studying marine biology. This illustrates how students in Study 4 showed skills of thinking within a particular thematic pattern (Lemke,

1990) and how, during the school year, they moved towards becoming science literate in this particular context.

To engage in assignments requiring students to discuss and to evaluate research and research results related to socioscientific issues is an important part of science teaching. Activities in which students get the opportunity to reason about research produced by others open the door to, in Lemke's (1990) words, the "community of people who *talk science*" (p. x). Moreover, Lemke argued that "scientific concepts are interlinked in their meanings, and that it is the use of systems of linked concepts that give scientific reasoning its power" (p. 99). Following this reasoning and the outcomes of my empirical studies, talking science is a central aspect of learning about socioscientific issues in which students need to integrate and evaluate different perspectives and approaches. This corresponds to a more general educational approach and underlines the need for the design of inquiry-based learning activities to provide students with possibilities for encountering such conceptual systems and for putting them to use.

Concluding remarks

In this thesis, I have investigated students' reasoning while engaged in tool-mediated activities. My intention has been to contribute with knowledge about the complexity involved in such activities and contexts. Informed by a sociocultural perspective on learning, my research combines analyses of products (Study 1) and processes of students' learning activities (Studies 2, 3, and 4). In Study 1, my research builds on the analysis of an extensive naturalistic empirical material of the written responses by students when they were asked to design an experiment. A strength of my approach was the combination of this kind of data with process data. The process data in turn illustrate the kind of activities and discussions that evolved when the students were engaged in tool-mediated activities. Accordingly, these kinds of materials offered opportunities to analyse how the tools became integrated into the students' activities and how they provide a platform for what students do when they solve problems and seek knowledge.

The main data in this thesis have been collected in one specific upper secondary classroom. Although there are similarities between the tool-mediated activities in this classroom and those in other classrooms, every classroom is unique. Consequently, investigations of students' ongoing activities and discussions in only one classroom could be seen as a limitation. However, my intention was, for instance, not to compare the learning effects of student activities using digital technologies with similar work absent the use of such tools. Rather, the purpose was to design a case study of a regular classroom setting which focused on inquiry-based learning and which tried to illuminate how learning, thinking, and communication about the ocean develops when supported by digital tools. The results from Study 1, which demonstrated the difficulties of outlining an experiment in writing, was an interesting starting point from which to further investigate what activities evolved when students worked with the virtual lab in groups and what discussions were made possible in such activities. Furthermore, by applying a sociocultural perspective on learning, the analyses are directed towards interaction between students and the tools used. This implies that from my empirical findings, I cannot conclude whether the students learn more or less when using digital tools than they would have done otherwise. I can, however, point to signs of learning and illustrate the kinds of activities and reasoning that are made possible in tool-mediated activities.

As described earlier, the curricular context of the three studies, which constitute the main data in the present research, is upper secondary marine biology schooling. This, however, does not imply that the virtual lab and the carbon footprint calculator are useful in this specific context only; rather, the content is relevant also to other subjects (e.g., natural science and social science). In addition, due to their user-friendly interface, the tools are suitable as parts of instruction at different levels of the school system. However, further research is needed with respect to the implementation of such tools on a broader and more general level. It is obvious from my studies that students have experience with tools of this kind and that they are generally quite accessible for them; in this sense, a majority of students this age are digitally literate. Thus, they have digital habits that allow them to handle the interfaces quite readily, they quickly realize how to feed in values, and so on. However, my research underlines that instructional activities using digital tools when solving tasks require teacher support along the way. Related to this argument, it is important to acknowledge that the curricular goals and ambitions are not built into the tools themselves.

The potential of implementing digital technologies in instruction is something that has been discussed throughout this thesis. A virtual lab, for instance, enables the user to engage in sophisticated and complex experiments that would not have been possible in a traditional school lab. However, one must bear in mind that experiments that are being practised in virtual labs are examples of a more general content. For example, when the students carried out the experiment on sea urchin larvae, they ought to understand that this is an example of how marine organisms might be affected by ocean acidification. The issue of distinguishing the activities one engages in as examples of a more general content is a traditional pedagogical dilemma and not specifically connected with the use of the digital tools. The pedagogical dilemma of learning how to generalize will still be present and needs attention by the teacher.

To understand experimentation as a research method requires insights into several aspects; for example, the signifying characteristics of experiments, how to design and conduct them, and the kind of knowledge that can be obtained. Studies 1, 2, and 4 in this thesis provide examples of learning activities involving these different elements of scientific work. That is, the participants in the studies were required to design an experiment in order to give an answer to a specific problem, they practised an experiment, and they evaluated research results and scientific claims. As pointed out earlier in this thesis, several studies show that inquiry-based activities per se do not necessarily imply that students develop a scientific language. Students can learn to do science but not necessarily how to talk about it (Gyllenpalm, 2010; Lager-Nyqvist et al., 2011). The reason for this could be that the work of practising experimentation in a traditional school lab consists of many separate actions that have to be understood as parts of an overall activity with certain goals. Thus, the implementation of digital technologies in science teaching is interesting to investigate from this perspective as well; do students learn to design and engage in experiments, and do they also learn to talk about this as a coherent and valid approach to investigating the world?

As stressed by Leach, Raworth, and Rockström (2013), considering that a major challenge in the 21st century is to ensure "that the total pressure on Earth systems remains within planetary boundaries" (p. 85), education must take on the role of enhancing young people's knowledge and awareness of environmental topics that concern climate change. Currently, there are developments of digital technologies offering learning content about contemporary issues that are of great societal concern for people. Digital tools can be used as powerful resources that enable citizens to argue about environmental topics on societal and political levels. Similarly, the use of digital tools can facilitate the possibilities for addressing complex environmental issues in classroom settings. The knowledge generated by students about, for instance, human-driven climate change is highly relevant outside the school situation as well. In fact, increasing public understanding of the relationships between human activities and their consequences for the environment is one of the most significant goals of popular education in our time. Knowledgeable and critical citizens are necessary prerequisites for responsible political action and for a sustained commitment to changing our life styles, and education has an obvious responsibility to serve as a bridge between science and everyday life.

9. Swedish summary

Att lära sig resonera om frågor som rör miljökunskap. Digitala verktyg, access points[21] till kunskap och vetenskaplig förståelse.

Inledning

Avhandlingens övergripande intresse är riktat mot skärningspunkten mellan hur elever lär om miljöfrågor och den roll som digitala teknologier kan spela i sådana undervisningskontexter. Under de senaste decennierna har digitala verktyg kommit att användas i allt fler av våra vardagliga aktiviteter, både i privatlivet men också i arbetslivet. Detta gäller även inom skolan där dessa verktyg har fått ett allt större utrymme i undervisningen (jfr Erstad & Sefton-Green, 2013; Lantz-Andersson & Säljö, 2014). Digitala teknologier öppnar upp för nya sätt att presentera och bearbeta information som skiljer sig från traditionellt textbaserade material. De är, bland annat, multimodala och möjliggör olika sätt att dynamiskt integrera bilder, ljud och animeringar som medför nya förutsättningar för organiserandet av lärandeaktiviteter. De är också interaktiva; det vill säga de svarar på initiativ som användaren tar. De digitala verktygen samspelar på så vis med elevers tillgång till information och med deras förståelse och sätt att resonera kring vad de läser och ser. Historiskt sett har implementeringen av digitala teknologier i undervisningen inte varit helt okomplicerad. Även om lärare i viss mån har introducerat dessa resurser, har de oftast använts inom redan etablerade och traditionella arbetsformer (Cuban, 2001; Säljö, m. fl., 2011). På så sätt har teknologin blivit ett inslag i en redan vedertagen praktik utan att förändra den nämnvärt. Tidigare studier pekar på vikten av hur lärare organiserar sin undervisning i sådana miljöer för att de digitala verktygens potential ska kunna tas till vara och för vad som blir möjligt för eleverna att lära sig med sådana resurser (t.ex., Greiffenhagen, 2008).

Miljökunskap har blivit ett allt viktigare ämne i skolor i många länder runt om i världen (Stokes m. fl., 2001). I linje med UNESCO:s (1975, 1977, 2004)

[21] Termen "Access points" handlar om att få en ingång till, eller tillträde till komplex kunskap. Tyvärr finns det ingen lämplig svensk översättning av termen.

definition av ämnet betonar den svenska läroplanen (2011) värdet av att utbilda elever i miljöfrågor och förbereda dem på att själva kunna ta en aktiv roll för att stödja en hållbar utveckling. Som kunskapsområde är miljökunskap både intressant och utmanande då det är ett ämne som kräver insikter inom flera områden. Många miljöfrågor, exempelvis global uppvärmning och genetiskt modifierade organismer, benämns i litteraturen som socioscientific issues. Dessa frågor kännetecknas av att de är öppna och har flera möjliga svar och lösningar (Mäkitalo m. fl., 2009; Sadler m. fl., 2007). De erbjuder också en arena för elever att utforska etiska principer, förhandla om sociala och politiska dilemman och reflektera över beslut som har sin grund både inom vetenskapliga, ekonomiska, politiska och etiska domäner (Dawson, 2015; Sadler m. fl., 2007; Sadler & Zeidler, 2005; Åberg, 2015).

Lärandeaktiviteter som handlar om socioscientific issues inbegriper ofta inquirybaserad pedagogik (Minner m. fl., 2010). Idén om att lära genom inquiry artikulerades av John Dewey för över 100 år sedan (1997). Tanken bakom inquiry är att om elever lär sig hur forskare formulerar frågor, hur dessa frågor studeras och vilka slutsatser som kan dras, kommer de att förstå grunden till vetenskap och vetenskaplig kunskap. Att förstå logiken i hur man observerar och kodar världen på vetenskapligt relevanta sätt, både vad gäller praktiskt genomförande men också att i tal och skrift kunna prata om vetenskapliga undersökningar, är en betydande del i utvecklingen av science literacy (Wickman, 2004). Begreppen science literacy och scientific literacy syftar båda till en naturvetenskaplig allmänbildning men med lite olika innebörder (Säljö, m. fl., 2011). I denna avhandling används termen science literacy i diskussioner som relaterar till hur elever resonerar i inquirybaserade aktiviteter. Scientific literacy används när elever arbetar med socioscientific issues som rör miljöfrågor.

Klimatförändringen är, som tidigare nämnts, ett intressant pedagogiskt område som är högaktuellt i vår tid. Frågor som rör klimatförändring utgör ett specifikt fokus i min avhandling där intresset är att studera elevers läraktiviteter inom områdena havsförsurning och människors miljöpåverkan i form av koldioxidutsläpp.

Miljökunskap är ett relativt nytt ämne i skolan och vilar därför inte på lika långa undervisningstraditioner som exempelvis matematik och språk. Detta innebär att miljökunskap kan ses som potentiellt mer mottagligt för möjligheter att implementera nya verktyg och arbetssätt, och inom ramen för detta ämne introduceras också kontinuerligt nya digitala verktyg (se Fauville

m. fl., 2014 för en litteraturöversikt om användningen av digitala verktyg i miljökunskap). I denna avhandling är utgångspunkten att studera redskapsmedierade aktiviteter i en kontext där elever lär och resonerar om miljöfrågor. Den forskning som rapporteras fokuserar på elevers aktiviteter i relation till två specifika digitala verktyg: ett virtuellt labb (havsförsurningslabbet) och en koldioxidkalkylator.

Avhandlingens empiriska material är kopplat till forskningsprojektet Inquiry-to-Insight (I2I). I2I var ett samarbete mellan forskningsgrupper från Utbildningsvetenskapliga fakulteten vid Göteborgs universitet, Sven Lovén centrum för marina vetenskaper vid Göteborgs universitet, Stanford University och Hopkins Marine Station i Kalifornien som pågick mellan 2008 och 2013. Syftet med projektet var att utveckla digitala verktyg, socialt nätverkande samt pedagogik riktad mot miljöfrågor. Marinbiologer från Stanford University och Göteborgs universitet har designat och utvecklat det virtuella labbet och koldioxidkalkylatorn. Det empiriska materialet som min forskning bygger på har genererats av elevers aktiviteter med de båda verktygen samt test och uppgifter som är designade av marinbiologer inom I2I-projektet.

Teoretiskt tar avhandlingen sin utgångspunkt i ett sociokulturellt perspektiv på lärande. Den innehåller fyra empiriska studier vilka ingår i sammanhang där elever lär om miljöfrågor som specifikt rör konsekvenserna av havsförsurning och koldioxidutsläpp. Det analytiska intresset i Studie 1 är *produkter* av elevernas lärande. Analysen i denna studie fokuserar på elevernas skriftliga beskrivningar av hur de skulle designa ett experiment inom området havsförsurning. Detta var en uppgift de löste både i ett för- och ett eftertest i en empirisk studie som genomfördes i USA. Mellan de båda testtillfällena utförde eleverna ett experiment i det virtuella labbet. I studierna 2, 3 och 4 rör det analytiska intresset *processer*, det vill säga, hur elever arbetar i aktiviteter där de använder ett virtuellt labb, en koldioxidkalkylator eller skriver rapporter där de utvärderar den vetenskapliga validiteten i forskning som gäller havsförsurning. Det sistnämnda empiriska materialet fokuserar på elevernas interaktion i klassrummet, deras redskapsmedierade och kollaborativa aktiviteter och diskussioner samt de skrivna svar som de producerar.

Bakgrund

Den tidigare forskning som redovisas diskuterar två områden. Det första forskningsområdet utgörs av studier om användningen av virtuella labb och koldioxidkalkylatorer i undervisning. Det andra tar sin utgångspunkt i forskning om miljökunskap och lärande om socioscientific issues och science literacy.

Många studier av virtuella labb fokuserar på att utveckla dessa verktyg och fokus ligger därmed på själva designprocessen och olika resursers för- och nackdelar. En ytterligare vanligt förekommande typ av forskning fokuserar på effekter av användningen av virtuella labb där elevers virtuella laboratoriearbete ofta jämförs med liknande aktiviteter i ett traditionellt skollabb. Syftet med denna typ av forskning är att få kunskap om huruvida elever lär bättre, sämre eller lika bra med virtuella labb jämfört med traditionella skollabb. Utgångspunkten i min forskning är dock att, för att få insikt i hur elever skapar mening och lär i de sammanhang de använder virtuella labb i skolan är det nödvändigt att studera de aktiviteter som uppstår då de interagerar med varandra och med verktyget. Således fokuseras det virtuella labbarbetet som sådant, eller med andra ord, de aktiviteter som utvecklas när elever använder virtuella labb.

Virtuella labb är ett exempel på verktyg som bidrar till att skapa intressanta möjligheter att lära och resonera i miljökunskap. Ett annat relevant exempel är koldioxidkalkylatorer. Forskning om användningen av koldioxidkalkylatorer i undervisning visar att dessa verktyg fungerar som pedagogiska resurser vilka bidrar till att elever får upp ögonen för och blir medvetna om sin egen miljöpåverkan (Cordero m. fl., 2008; Hopkinson & James, 2010; Kemppainen m. fl., 2007; McNichol m. fl., 2011). I ett stort antal studier om elevers användning av virtuella labb jämförs, som redan nämnts, aktiviteter med det digitala verktyget med liknande traditionellt utformade aktiviteter. När det gäller forskning om implementering av koldioxidkalkylatorer i undervisningen görs inte sådana jämförelser. Detta beror till stor del på att koldioxidkalkylatorn innehåller komplexa uträkningar av koldioxidutsläpp orsakade av människors livsstilsval som är mycket svåra, eller rent av omöjliga att utföra med papper och penna. Dessutom är sådana komplicerade uträkningar alltför tidskrävande och därför olämpliga som aktiviteter i klassrummet. Användningen av koldioxidkalkylatorer i undervisningen utgör således en ny läraktivitet som inte gör jämförande studier möjliga (Brody &

Ruy, 2006; Cordero m. fl., 2008; Hopkinson & James; Kemppainen m. fl., 2007; McNichol m. fl., 2011).

I avhandlingen problematiseras forskning om elevers lärande om socioscientific issues. En stor del av denna forskning fokuserar på att bedöma elevers svar på stora och öppna frågor som exempelvis ”Vad är växthuseffekten?” eller ”Vad är klimatförändring?”. Forskningen inom det sociokulturella perspektivet undersöker istället företrädesvis hur elever hanterar ovanstående typer av frågor genom att analysera deras interaktioner i klassrummet (se exempelvis Jakobsson m. fl., 2009). Att studera elevers svar på omfattande och öppna frågor bidrar med kunskap om hur elever tolkar och förstår dessa frågor medan studier av elevers resonerande då de deltar i gruppdiskussioner bidrar till insikter i hur de skapar mening då de arbetar med komplexa socioscientific issues, samt hur och om de är på väg att appropriera ett vetenskapligt språk som används för att förstå och förklara dessa frågor.

Syfte och frågeställningar

Avhandlingens övergripande syfte är att undersöka redskapsmedierade aktiviteter i en kontext där elever studerar miljökunskap. Som tidigare nämnts är det två digitala verktyg som har studerats som en del av elevernas utbildning: ett virtuellt labb och en koldioxidkalkylator. Med utgångspunkt i ett sociokulturellt perspektiv på lärande syftar forskningen till att studera hur dessa specifika verktyg ger förutsättningar för och stödjer elevers sätt att resonera om vetenskap, å ena sidan, och å andra sidan, om miljöfrågor som rör klimatförändring. Studiens analysenhet är således elevers resonerande i sådana typer av redskapsmedierade aktiviteter. Med utgångspunkt i avhandlingens övergripande intresse har två forskningsfrågor formulerats:

- På vilket sätt samspelar digitala redskap med elevers resonerande och lärande om vetenskaplig kunskap och miljöfrågor?
- Vilka implikationer har användningen av dessa redskap för elevernas utveckling av science literacy?

Avhandlingen består av två delar. Den första delen innehåller en forskningsbakgrund om digitala teknologier och miljökunskap, teoretiska och metodologiska perspektiv, en sammanfattning av studierna samt en diskussion. Den andra delen utgörs av de fyra empiriska studierna[22].

Teoretiskt perspektiv

Som redan nämnts tar avhandlingen sin teoretiska utgångspunkt i ett sociokulturellt perspektiv på lärande dessutom används Deweys idéer om lärande genom inquiry. Inom det sociokulturella perspektivet ses lärande som situerat, vilket innebär att kunskap och lärande både är manifesterade i och utvecklas i sociala praktiker (Lave & Wenger, 1991; Säljö, 2005). Centralt för detta teoretiska ramverk är också idén om att människor approprierar eller tillägnar sig kulturella redskap i sociala praktiker (Säljö, 2005; Vygotsky, 1978; Wertsch, 1998). Lärande blir på så vis en fråga om att utveckla färdigheter som gör att man kan använda kulturella redskap i situerade praktiker på relevanta och produktiva sätt. I ett sociokulturellt perspektiv medierar redskapen världen för oss i olika aktiviteter (Säljö, 2005). Kulturella redskap gör det möjligt för människor att behärska abstrakta aktiviteter och funktioner som att minnas, räkna, jämföra och analysera vilket annars skulle varit svårt eller i många fall till och med omöjligt att utföra (Vygotsky, 1997). Kulturella redskap utgör på så sätt resurser som stöttar olika typer av resonemang och medierar kunskap på specifika sätt. Det virtuella labbet och koldioxidkalkylatorn är exempel på medierande redskap som utgör utgångspunkt för elevers förståelse och möjligheter att resonera om havsförsurning och klimatförändring.

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1) Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013). Exploring nature through virtual experimentation. Picking up concepts and modes of reasoning in regular classroom practices. *Nordic Journal of Digital Literacy, 3*(8), 139-156.

2) Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013). Virtual labs as context for learning – continuities and contingencies in student activities. In E. Christiansen, L. Kuure, A. Mørch, & B. Lindström (Eds.), *Problem-based learning for the 21st century. New practices and learning environments* (pp. 161-189). Aalborg: Aalborg University Press.

3) Edstrand, E. (2015). Making the invisible visible: how students make use of carbon footprint calculator in environmental education. *Learning, Media and Technology, 41*(2), 416-436.

4) Edstrand, E., Lantz-Andersson, A., Säljö, R., & Mäkitalo, Å. (2016). Deciphering the anatomy of scientific argumentation: the emergence of science literacy. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39-60). Rotterdam, The Netherlands: Sense Publishers.

Ett intressant fenomen som är relaterat till medierande resurser såsom virtuella labb och koldioxidkalkylatorer är att de bygger på vetenskapliga och tekniska kunskaper som till stora delar är dolda eller ”blackboxed” (Latour, 1999) för användaren. Att verktygen fungerar som en black box innebär att det finns en mängd tekniska funktioner som är osynliga och som användaren inte behöver vara uppmärksam på. Med andra ord, användaren kan använda verktygen på ett ändamålsenligt sätt utan att ha kunskap om funktioner såsom hur programmeringen har skett eller vilka databaser som har använts. I en undervisningskontext kan det däremot vara av betydelse att elever förstår vissa av de begrepp och tillvägagångssätt som är blackboxed. Här har läraren en viktig roll i att packa upp de funktioner i verktyget som är relevanta för det innehåll som eleverna ska lära sig något om.

Deweys (1938) tankar om lärande genom inquiry spelar en central roll i den här avhandlingen. Begreppet används för att analysera läraktiviteter som har som syfte att främja insikter och färdigheter kopplade till elevers utveckling av science literacy. Dewey var kritisk mot sättet på vilket utbildning bedrevs. Vad han opponerade sig mot var att undervisningen i huvudsak fokuserade på att lära ut statiska produkter (begrepp, fakta, lagar osv.). Enligt Dewey borde undervisningen i stället handla om att lära ut hur kunskap blir till och vad som utmärker vetenskapligt arbete. Med andra ord, för att kunna formulera hypoteser och undersöka dessa, så behöver elever kunna identifiera vad ett undersökningsbart problem är. Processen att identifiera vad ett problem är och hur det kan undersökas är centrala delar av inquiry (Talisse, 2002). Detta innebär att forskningen i den här avhandlingen fokuserar på hur elever förstår problem, om de kan formulera problem som är möjliga att undersöka på ett vetenskapligt sätt, hur de tolkar data och liknande frågor. Begreppet inquiry används därmed för att konceptualisera hur elever lär genom problembaserade aktiviteter.

Studiens kontext

De empiriska data som ligger till grund för avhandlingens första studie utgörs av amerikanska elevers (12-18 år) skrivna svar på en fråga som gavs vid ett för- och eftertest. Studien bygger på analyser av elevernas svar på en öppen fråga i testet där de ombads designa ett experiment för att kunna besvara en miljöfråga. Studierna 2, 3 och 4 bygger på videoinspelningar av en svensk gymnasieklass där eleverna läser ett marinbiologiskt program.

Det virtuella labbet och koldioxidkalkylatorn har del i de fyra studierna på olika sätt. I den första studien utgörs, som tidigare nämnts, det empiriska materialet av en öppen fråga som över 500 amerikanska elever svarade på vid två tillfällen. Mellan de båda testen arbetade eleverna med det virtuella labbet. I det videoinspelade materialet av den svenska gymnasieklassen arbetar eleverna i den andra studien med det virtuella labbet. Studie 3 baseras på videoinspelningar av elevers gruppdiskussioner där de diskuterar sina resultat från koldioxidkalkylatorn. De digitala verktygen har på så sätt en central roll i studierna 1, 2 och 3. I Studie 4 utvärderar eleverna forskningsresultat som på olika sätt beskriver förändringar i havsmiljön. Redskapen har således ingen aktiv roll i själva aktiviteten, däremot har eleverna under skolåret använt både det virtuella labbet och koldioxidkalkylatorn.

Det virtuella labbet gör det möjligt för elever att studera en värld av organismer vars livsvillkor är påverkade av klimatförändringar och koldioxidutsläpp. Koldioxidkalkylatorn är en kalkylator som beräknar koldioxidutsläpp kopplade till elevernas inmatade svar i form av uppskattningar av deras individuella livsstilsaktiviteter. Kalkylatorn är på så vis en materiell artefakt där eleverna får ut ett värde i form av ett fotavtryck, eller ett ”carbon footprint”. Detta värde kan därefter användas som utgångspunkt i diskussioner, att förhålla sig till och att göra jämförelser med. De båda redskapen är också exempel på verktyg som inbjuder till aktiviteter såsom att testa och manipulera. Aktiviteter som inkluderar användning av sådana redskap möjliggör således andra aktiviteter än de som möjliggörs med traditionell media såsom textböcker.

Metoder

Materialet till studie 1 består av elevernas skrivna svar på den enda öppna frågan (utav 17 frågor) i för- och eftertestet som nämnts tidigare. För analysen samplades 80 elevers svar från båda tillfällena. I den utvalda öppna frågan ombads eleverna att skriftligen beskriva hur de skulle designa ett experiment som kunde ge svar på ett problem, som var formulerat på följande sätt:

> You are an environmental scientist who is hired to complete an environmental impact report for a proposed project. Tropical Fisheries of Hawaii plans to open a fish hatchery on the Luau River, and the river opens to a bay with a large coral reef. Biologists are concerned that water discharge from the hatchery could impact the pH of the river in the bay.

> What sort of an experiment could you do to see if a change in pH might have an effect on the growth of the coral?

Analysen fokuserade på om och hur eleverna approprierade ett vetenskapligt språk (dvs. hur de använde termer/begrepp som urval, kontrollgrupp m.m.), och på vilket sätt de resonerade om hur man organiserar ett experiment efter att ha arbetat med det virtuella labbet. Lemkes (1990) begrepp "talking science" är centralt i analyserna av elevernas resonerande om vilken typ av experiment de behöver designa för att kunna besvara frågan. Talking science innebär att eleverna behöver ha insikt i en specifik vetenskaplig terminologi (exv. urval, kontrollgrupp, observation) och kunna kombinera begrepp och uttrycka sig på ett relevant vetenskapligt sätt. Vid analysen av elevsvaren valdes således ett antal vetenskapliga begrepp ut, vilka var baserade på resultat från tidigare forskning inom området science literacy samt den terminologi som används i det virtuella labbet. Svaren studerades också i enlighet med hur explicit och till vilken grad av precision de närmade sig en redogörelse för ett relevant och informativt experiment som möjliggjorde att frågan kunde besvaras.

Till avhandlingens studier 2, 3 och 4 har ungefär 12 timmars videoinspelningar analyserats. I studierna 2 och 4 arbetade eleverna tillsammans i grupp där varje grupp hade en bärbar dator till sitt förfogande. För inspelningarna användes en kamera per grupp som var placerad snett bakom eleverna. Detta för att kunna fånga datorskärmen men också för att kunna få med elevernas agerande i form av pekningar på skärmen och gester till varandra inom gruppen. Dessutom spelades elevernas aktiviteter på datorskärmen in med programmet ScreenFlow. I materialet där eleverna arbetade med det virtuella labbet (Studie 2) hade läraren en kort introduktion i början av lektionen där delar av havsförsurningen och dess konsekvenser presenterades. Denna introduktion spelades även in på video. I det material (Studie 3) där eleverna i grupp diskuterar sina koldioxidutsläpp var kamerorna placerade framför varje grupp.

Videoinspelningar gör det möjligt att studera detaljer i interaktionen. I denna avhandling innebär detta att det genom att studera elevernas interaktion varit möjligt att förstå vilken typ av aktiviteter som uppkommer när de arbetar med virtuellt labbarbete i miljökunskap, hur de använder en koldioxidkalkylator som en resurs för att resonera om handlingar i den egna livsstilen och hur de förstår och kritiskt granskar vetenskapliga påståenden. Den metod som har använts i analysarbetet är interaktionsanalys (Jordan &

Henderson, 1995; Raudaskoski, 2006). Med utgångspunkt i interaktionsanalys har aktiviteter i form av tal, icke-verbal kommunikation och människors interaktion med artefakter och teknologier inom en kollaborativ lärmiljö analyserats. Själva metoden har sina rötter i etnografi (exempelvis deltagande observationer) och andra traditioner som också inkluderar människors användning av icke-verbala resurser i interaktion, såsom konversationsanalys och etnometodologi (ex. Crook, 1994; Goodwin & Heritage, 1990; Sacks m. fl., 1974; Stahl m. fl., 2006).

I analysarbetet var det betydelsefullt att fånga alla aktiviteter som ägde rum när eleverna arbetade med de olika uppgifterna (Jordan & Henderson, 1995). Transkriberingen var därför en process av att noga titta på videoinspelningarna för att studera tal, icke-verbal kommunikation och aktiviteter på datorskärmen. Transkriptionerna av videoinspelningarna är inspirerade av Jeffersons (1984) transkriptionskonventioner som är vanligt förekommande i interaktionsanalys.

Sammanfattning av delstudierna

I studie 1 diskuteras användningen av virtuella labb i undervisningen om miljöfrågor och mer specifikt havsförsurning. Syftet med aktiviteten är att eleverna förutom att utveckla förståelse om havsförsurning ska erbjudas en kontext där de kan lära sig om experiment som forskningsmetod. Som beskrivits ovan består empirin i studie 1 av mer än 500 elevers skrivna svar på en öppen fråga i ett för- och eftertest. Två olika analyser av elevernas svar vid de båda tillfällena utfördes. Den ena rörde användningen av vetenskapliga begrepp och den andra är ett försök att undersöka utmärkande drag i elevernas resonerande i termer av hur nära de kom att föreslå ett experiment som skulle ge information om förändrad vattenkvalitet. Resultaten visar att eleverna använder sig av fler vetenskapliga begrepp vid andra tillfället och att nästan hälften av eleverna utvecklade sitt sätt att beskriva ett experiment som kunde svara på frågan. I analysen beskrivs att 47,5 procent av elevernas svar kategoriserades på samma sätt vid de båda tillfällena och att 43,5 procent av eleverna utvecklade sitt resonerande i eftertestet och kom närmare att precisera ett experiment. Ändå visar resultaten på en övergripande nivå att få av dem kunde föreslå och beskriva ett experiment. En av poängerna i studien är att digitala redskap såsom virtuella labb inte nödvändigtvis bidrar till att eleverna utvecklar en förståelse för vad det innebär att designa ett experiment.

Resultatet visade att sådan förståelse inte uppstår på ett enkelt sätt enbart genom användning av det virtuella labbet utan kräver insikter som innebär att förstå den roll ett experiment spelar som en del av en vetenskaplig studie av ett problem.

I likhet med Studie 1 är bakgrunden till Studie 2 ett intresse för virtuella labb som en kontext för att lära om havsförsurning. Studien bygger på frågor som rör vilka typer av aktiviteter som utvecklas när elever arbetar med virtuella labb i miljökunskap och vilka konsekvenserna blir för interaktion och kunskapsdelning mellan elever i sådana kontexter. Det empiriska materialet består av videoinspelningar av gymnasielever som tillsammans i grupp arbetar med ett virtuellt labb. Resultaten belyser hur de använder det virtuella labbet på olika sätt. Det virtuella labbet ger å ena sidan tillgång till sofistikerad kunskap om miljön. Å andra sidan, och med anledning av att många funktioner i det virtuella labbet är osynliga, eller ”blackboxed” (Latour, 1999), visar analyserna att eleverna kontinuerligt skiftar fokus mellan teknologin och det vetenskapliga innehållet medan de arbetar. Studien bekräftar på ett tydligt sätt genom observationer att det pedagogiska värdet av en sådan virtuell lärmiljö inte bestäms av det digitala verktyget självt utan snarare av de aktiviteter som eleverna skapar. Därmed blir det tydligt att läraren har en viktig roll för att hitta möjligheter att gå in och stötta elevernas arbete med virtuella labb.

Studie 3 har ett särskilt intresse för användningen av koldioxidkalkylatorer i en kontext där eleverna lär om miljöfrågor och klimatförändring genom att räkna ut och diskutera sina carbon footprints. Mer specifikt bidrar studien med insikter i hur sådana verktyg bidrar till att eleverna utvecklar olika sätt att resonera om miljön. Det empiriska materialet består av videoinspelningar av svenska gymnasieelevers gruppdiskussioner. Eleverna arbetade under en halvdag med aktiviteter relaterade till användningen av en koldioxidkalkylator. Den första delen av lektionen var vigd åt individuellt arbete med verktyget där eleverna räknade ut sina carbon footprints och i den andra delen av lektionen diskuterade de resultaten av sina fotavtryck tillsammans i olika grupper. Fokus för analysen är gruppdiskussionerna och vilken typ av resonerande om miljön som blir möjliga genom att eleverna har använt kalkylatorn. Studien undersöker elevernas ställningstaganden eller ”accounts” (Mäkitalo, 2003) i relation till hur de diskuterar och jämför sina fotavtryck. Med andra ord, hur eleverna i sina diskussioner förklarar och försvarar aktiviteter kopplade till sin livsstil. Resultaten visar att koldioxidkalkylatorn stöttar olika sätt att resonera om den egna miljöpåverkan. Verktyget erbjuder en ny arena för eleverna att utveckla en förståelse för sambandet mellan klimatförändring och människors aktiviteter. Resultaten visar hur eleverna kvantifierar, analyserar och jämför koldioxidutsläpp både på en individuell nivå men också på en systemnivå (mellan länder). Således medierar verktyget aspekter kring miljön som annars inte vore möjliga att uppfatta; verktyget gör det osynliga synligt.

I likhet med studierna 1 och 2 är intresset i den fjärde studien elevers lärande genom inquirybaserade aktiviteter. Det empiriska materialet består av videoinspelningar av elever som tillsammans i grupp skriver en rapport där de kritiskt granskar den vetenskapliga validiteten i forskningsresultat som presenteras i två korta artikelsammanfattningar (abstracts). Artikelsammanfattningarna behandlar relationen mellan förändringar av pH-nivån i havet och en ökad mängd maneter. Centralt i analyserna av hur elever resonerar och argumenterar om validiteten i dessa vetenskapliga forskningsresultat är Lemkes begrepp ”talking science”. Analyserna visar att eleverna i flera fall pekar på brister i artikelsammanfattningarna utan att förklara varför dessa skulle påverka validiteten i undersökningarna. I artikeln diskuteras att detta resultat kan förstås på olika sätt: att eleverna inte motiverar sin kritik kan dels bero på att de tycker att bristerna är uppenbara och dels kan det bero på att eleverna finner det svårt att formulera det identifierade problemets underliggande brister. Att kommunicera vetenskap och vetenskapliga metoder är färdigheter som elever behöver öva på genom återkommande inquirybaserade aktiviteter (Bybee, 2000; Gyllenpalm, 2010; Haret m. fl., 2000; Lager-Nyqvist, 2011). Resultaten visar också hur eleverna i arbetet med att dekonstruera forskningsresultaten i artikelsammanfattningarna formulerar sin kritik genom att ställa frågor, uttrycka tvivel och föreslå alternativa metoder och förklaringar. För att stötta sina resonemang använder de marinbiologiska termer och kunskap om havet. Slutsatsen är att denna typ av kunskap om och begreppskompetens relaterat den specifika domän som är relevant för en undersökning är viktigt att ha när det gäller att förstå vilka variabler som bör tas i beaktande när ett experiment ska designas.

Diskussion

Vad som gör det virtuella labbet och koldioxidkalkylatorn till exempel på specifikt intressanta redskap är att eleverna med hjälp av dessa får tillträde till komplicerade aktiviteter och kunskapsdomäner. Redskapen möjliggör diskussioner om vetenskapliga metoder och miljöfrågor som rör havsförsurning och koldioxidutsläpp utan krav på några djupgående förkunskaper. De digitala redskapen bidrar med andra ord till att dessa resurser erbjuder access points (Giddens, 2002; cf. Säljö, 2010) till komplexa och sofistikerade observationer och analyser om vetenskaplig kunskap och miljöfrågor. I de tre studierna (1, 2 och 3) där eleverna arbetar med det virtuella labbet och koldioxidkalkylatorn är ett centralt argument att de specifika verktygen möjliggör aktiviteter som annars vore svåra eller omöjliga att organisera. Det experiment som eleverna arbetar med i det virtuella labbet skulle vara svårt att genomföra i ett traditionellt skollabb då experimentet kräver att eleverna följer klimateffekter över en längre tidsperiod och då de i labbet kan jämföra sina resultat med statistisk data från autentisk forskning. När det kommer till de aktiviteter som är relaterade till användningen av koldioxidkalkylatorn, är den kunskap som medieras genom användningen av redskapet mångfasetterad och uträkningarna är alltför komplexa att klara utan tillgång till redskapet. På så sätt öppnar verktygen upp för nya arenor för lärande och resonerande om forskning och miljöfrågor som rör klimatförändring som går bortom vad ett traditionellt skollabb eller aktiviteter med papper och penna skulle kunna erbjuda.

Vid sidan av sådana access points till kunskap, pekar min forskning också på att det finns dilemman kopplade till elevers användning av digitala verktyg i en undervisningskontext. Dessa dilemman rör den kunskap och de konceptuella antaganden som i verktygen är blackboxed. Ett exempel från Studie 3 är att eleverna jämför sina carbon footprints med det svenska medelvärdet. Sett ur ett lärandeperspektiv blir det relevant att packa upp vad det svenska medelvärdet representerar på en global nivå då eleverna i studien använder detta för att resonera på ett kompensatoriskt sätt. Det svenska medelvärdet ligger på 7305 kilogram koldioxidutsläpp per år. Om man jämför det med det värde som anses vara globalt hållbart, 1000 kilogram per år, så ser vi att det svenska medelvärdet inte är i närheten av en hållbar nivå. Att utveckla en förståelse för sambanden mellan personliga handlingar och deras effekt på miljön i form av koldioxidutsläpp kan dock ses som ett första steg i att utveckla en förståelse för klimatförändringar i riktning mot en mer hållbar utveckling. Ett viktigt nästkommande steg skulle vara att förstå vad aktiviteten av att räkna ut det personliga koldioxidutsläppet representerar i en värld utanför verktyget. Eleverna behöver därmed förstå sin egen miljöpåverkan som en del i ett större system. Genom att eleverna utvecklar ett systemtänkande blir det inte längre rimligt att använda ett lägre koldioxidutsläpp som kompensation för att göra en flygresa. För när det gäller det övergripande målet att utbilda elever i hållbar utveckling behöver alla handlingar i den egna livsstilen granskas.

Resultaten från min forskning visar att digitala redskap ger upphov till lärande samtidigt som de också förutsätter mycket, exempelvis förståelsen av vad ett experiment är. Vad som blir tydligt i analyserna av elevernas resonerande under arbetet med det virtuella labbet är att de i den del som rör aspekter av havsförsurningen använder sig av lärarens introducerande lektion om havsförsurningens konsekvenser. Det empiriska materialet visar hur eleverna approprierar delar av lärarens resonemang och exempel genom att göra dem till sina egna (Wertsch, 1998). Lärarens introduktion stöttar på så vis eleverna i deras förståelse av komplicerade kemiska processer av havsförsurning.

De svenska gymnasieeleverna som deltar i studierna 2, 3 och 4 arbetade med inquirybaserade aktiviteter under ett skolår. Det empiriska materialet i Studie 4 är insamlat i slutet av skolåret vilket innebär att eleverna tillsammans med andra aktiviteter redan har arbetat med det virtuella labbet och koldioxidkalkylatorn. De har deltagit i aktiviteter där de tillsammans i grupp har resonerat om vetenskap och miljöfrågor samt besökt en marinstation. Den uppgift som eleverna arbetar med inom ramen för den fjärde studien handlar om att diskutera och resonera validiteten i två vetenskapliga artikelutdrag som undersöker sambandet mellan ett ökat manetbestånd och ett förändrat pH-värde i havet. Analysen av elevernas diskussioner visar hur de i sina resonemang använder en domänspecifik kunskap genom att applicera marinbiologiska termer om havet kopplade till marina organismer och havsförsurning. På så sätt visar eleverna färdigheter i att tänka och resonera utifrån ett specifikt tematiskt mönster (Lemke, 1990) som pekar på att de under skolåret utvecklats inom science literacy.

Slutsatser

Användning av digitala teknologier i undervisning bidrar till aktiviteter som kan ses som nya möjligheter för lärande. Samtidigt pekar studierna av elevernas arbete med verktygen också på dilemman som är kopplade till sådana verktygsmedierande aktiviteter. Något som är viktigt att uppmärksamma är att experiment som genomförs i virtuella labb är ett exempel som görs för att illustrera ett mer övergripande innehåll. I studierna där eleverna arbetar med havsförsurningslabbet så behöver eleverna förstå att experimentet med sjöborrelarverna fungerar som ett exempel på hur marina organismer kan komma att påverkas av havsförsurning. Att skilja på vad som är exempel och övergripande innehåll är ett traditionellt undervisningsdilemma som inte löses av användningen av ett digitalt verktyg. Min forskning understryker således att den pedagogiska inramningen, och lärarens roll att lyfta den här typen av frågor till en meta-nivå, är central för att guida eleverna till en mer generell och övergripande förståelse för vad de specifika aktiviteter de gör är exempel på.

En förståelse för experiment som vetenskaplig metod kräver insikter i, bland annat, vad som kännetecknar experiment, hur experiment kan designas och genomföras och vilken typ av kunskap man kan få genom att utföra experiment. Studierna 1, 2 och 4 ger exempel på analyser av läraktiviteter där elever arbetar med dessa olika delar av vetenskapligt arbete, dvs. de har som uppgift att designa ett experiment, de utför ett virtuellt experiment och de utvärderar forskningsresultat och vetenskapliga påståenden. Ett flertal studier av elevers lärande i inquirybaserade aktiviteter visar att de kan lära sig att göra vetenskap på en praktisk nivå men att detta nödvändigtvis inte är det samma som att lära sig hur man talar om vetenskap (Gyllenpalm, 2010; Lager-Nyqvist et al, 2011). Orsaken till detta kan vara att utförandet av experiment i traditionella skollabb ofta består av ett flertal separata moment och handlingar vilket kan medverka till att den övergripande helheten, syftet med experimentet, förloras. Utifrån detta perspektiv blir det intressant att studera implementering av digitala teknologier i sådana inquirybaserade aktiviteter; lär sig elever att designa och utföra experiment och lär de sig tala om detta som en koherent och valid metod att undersöka världen?

Numera finns det en mängd digitala teknologier som syftar till att människor ska lära sig om samtida miljöproblem, såsom klimatförändring. Sådana digitala redskap kan användas som resurser för medborgare för att stötta diskussioner och argumenterande i frågor som rör miljöfrågor på en samhällelig och politisk nivå. Användningen av digitala teknologier underlättar möjligheterna att adressera komplexa miljöfrågor i klassrumspraktiker och de kunskaper som genereras kring den mänskliga miljöpåverkan är högst relevant även utanför en skolkontext. Medvetna och pålästa medborgare är en nödvändig förutsättning för att kunna påverka politiskt och för att driva frågor rörande förändring av människors livsstil till en mer miljövänlig och hållbar nivå.

10. References

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Appendix A

GÖTEBORGS UNIVERSITET
Institutionen för pedagogik och didaktik

GÖTEBORG UNIVERSITY *Department of Education*

Sidan 1(2)
2010-02-19

Till dig som är elev på Naturvetenskapsprogrammet med marinbiologisk inriktning på Gullmarksgymnasiet.

Medgivande gällande din medverkan i en forskningsstudie om lärandeaktiviteter i relation till digitala medier i skolan.

Studien som kommer att utföras är en utveckling av samarbetet med Kristineberg (Sven Lovén centrum för marina vetenskaper vid Göteborgs universitet) och Stanford University och ingår som en del i Wallenberg Global Learning Network projektet (WGLNII) som kallas Inquiry-to-insight (I2I) – *Investigating environmental problems and finding solutions: A testbed for virtual learnin.* För detta behöver vi ditt medgivande.

Nedan följer en kort presentation av projektet
Projektet bedrivs inom ramen för Göteborgs Universitets satsning på styrkeområden, där "Lärande" är ett av dessa. Den forskningssatsning inom Lärande (LETStudion – The University of Gothenburg Learning & Media Technology Studio) har som tema hur kunskap/expertis förändras, organiseras och kommuniceras i ett samhälle som blir alltmer teknik- och vetenskapsintensivt.

I projektgruppen ingår Roger Säljö, Annika Lantz-Andersson och Elin Johansson. Projektet har som några målsättningar att studera hur digitala teknologier används i relation till lärande. Vi är, till exempel, intresserade av att studera vad de olika digitala verktygen betyder för elevernas utvecklande av förståelse. Hur de olika verktygen används, vilka aktiviteter som blir framträdande i relation till dem och hur kommunikationen mellan studenterna i Sverige och USA ser ut.

För att dokumentera och analysera dessa lärandeaktiviteter kommer vi att använda oss av videoinspelningar. Annika Lantz-Andersson och Elin Johansson, kommer att under ett antal tillfällen under våren videofilma er när ni arbetar framför datorn och eventuellt deltar i andra aktiviteter i relation till I2I-projektet. Inspelningarna kommer sedan att användas inom forskningssammanhang samt i universitetets utbildningar av t.ex. nya lärare.

Allt arbete inom projektet kommer att ske i enlighet med Personuppgiftslagen (1998:204)*. Inspelningar kommer att förvaras på sätt som innebär att obehöriga inte kan få tillgång till dem. De elever och den personal som medverkar på videoinspelningarna kommer att vara anonyma i den rapportering som kommer ut av projektet. Namn kommer att ändras till fiktiva namn i de texter som publiceras av projektet.

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Om bilder från videoinspelningarna används vid rapporteringar kommer även de att anonymiseras så att personerna inte är möjliga att känna igen.
Vi vill betona att det är aktiviteter i relation till digitala medier i skolan, som vi är intresserade av och inte av enskilda elever eller lärare.

Kontaktpersoner vid frågor eller funderingar

Projektledare: Roger Säljö
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Forskare: Annika Lantz-Andersson
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Underskrift av elev
Eftersom denna typ av datainsamling kräver elevens medgivande ber vi dig att meddela i talongen nedan om du vill delta i detta forskningsprojekt eller inte. Medverkan i undersökningen är frivillig och du kan när som helst välja att avbryta medverkan.

\- -

Talongen lämnas in till Géraldine Fauville senast den 16 mars 2010

□ Ja, jag vill delta i studien. Inspelningarna får användas i studien samt i universitetets utbildningar och forskning.

□ Nej, jag vill inte delta i studien.

Datum:______________________ Elevens namn:____________________________

Elevens underskrift:________________________________

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Appendix B

The transcript convention applied is inspired by Jefferson's (1984) transcription conventions, which are commonly used in Conversation Analysis and ethnomethodological studies.

(.)	Shows just noticeable pauses.
TEXT	Indicates shouted or increased volume in speech.
<u>text</u>	Emphatic voice.
?	Inquiring intonation.
=	Indicates that there is no pause between two utterances.
°text°	Shows quiet talk.
((text))/[text]	Comments made by the researchers or a description of an activity.
(inaudible)	Inaudible word/s.
[text	Shows co-occurring talk where the square bracket indicates where the overlap starts.
tex:t	Shows that it is a stretched sound.
text-	A sharp cut-off.
text	Shows when a person writes and reads out loud what is being written.
te(h)xt	Talk with a laughing tone.