UNIVERSITY OF GOTHENBURG

Learning Science by Digital Technology

Students' understanding of computer animated learning material

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ABSTRACT

Digital learning material is associated with grand expectations among educational policy makers. Several attempts to introduce this new technology with the purpose of enhancing learning have been made in recent years. The schooling system has, however, been rather hesitant and not so ready to adopt this kind of teaching aid. The aim of this thesis is to probe into students' practical problems of understanding computerised science learning material involving animated sequences and educational text. For the purpose of this investigation an application describing the different events in the carbon cycle was developed. Two studies present analyses of students' reasoning and actions when working collaboratively with the task of making a written account of what is illustrated in the learning material. Both studies present examples of identified phenomena that were observed in more extensive empirical materials. The data is represented by video recordings of students' interaction with each other and the interface. Results from the studies reveal students' propensity for concentrating their attention to prominent characteristics of the animated display and to describe the animated models in correspondence to their resemblance of objects and occurrences in everyday life. In study II it is revealed how students, when constructing a written report of the described events, derive noun phrases from attentionally detected objects in the animation and from the educational text. In their effort to express themselves in colloquial language, when preparing their report, they deliberately select verbs that differ from the educational text. These courses of action together, contribute to give the report on what happens in the process a non-scientific explanation. It is concluded that students, lacking definite access to the relevant subject matter knowledge, consequently, cannot judge whether they have given an approvable account or not. Findings from the studies show that the school context with its explicit stipulations of assignments and implicit request for expressing oneself in your own words frames the learning and creates conditions for how the technology is used and understood. The results indicate that animated models of scientific concepts risk inferring misconceptions if students are left on their own with interpreting information from the learning material. Despite the detected problems of students' interpretations of the described phenomena, the results indicate that animated learning material can proffer an exploitable resource in science education. Such a prospect is the ability of animation to engage students in discussions of the subject and to make them recognise otherwise unobservable phenomena.

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Preface

Being a science teacher for more than 20 years I have often been in a quandary about the fact that a large proportion of my students do not learn the taught subject as intended. Even though having introduced a scientific concept with established teaching methods and thoroughly penetrated the subject it is frequently revealed on subsequent tests that many of my students still do not seem to have grasped the intended meaning. This experience has repeatedly made me ponder questions such as: is there something wrong with my teaching methods, am I bestowed with a selection of especially uneducable students or can there be other factors wrecking the intended learning outcome? Contemplating these conceivable explanations, I have come to some conclusions. Regarding my teaching methods, I consider them to be as already mentioned 'established', meaning methods that are prescribed in teacher training and regularly used in science education. Such methods for teaching a subject can be characterised by being built up of lessons presenting a concept, hands-on laboratory work and textbook studies. As for my students, they should constitute a fairly representative selection of students since I have taught at many schools including compulsory school, high school level and adult education. Another fact that has convinced me that the unsatisfactory results of my education cannot be especially attributed either to my capacity to teach or to my students' ability to learn is the fact that national surveys of students' knowledge have shown equally low results as these for students in my classes.

Technology in the service of education

My didactical interest has led me to search for new ways to enhance science education by means of teaching aids for representing scientific phenomena. Methods being traditional and established do not per se mean that they are perfect and flawless but just that they are widely practiced and refined for decades. Even though new teaching techniques have an obvious disadvantage over established methods and rely on sustained development for success (Bereiter, 2002), my conviction is that educators have to consider new devices for teaching. Bruner (1977) argues that ”there exist devices to aid the teacher in extending the student's range of experience, in helping him to understand the underlying structure of the material he is learning and dramatizing the significance of what he is learning” (p. 84).

Over the last decades we have seen the development and growth of the Internet, generating concepts as 'information technology' (IT) and 'information and communication technology' (ICT) frequently used in educational context. Such technologies proffer promising teaching aids and have raised great expectations among policy makers for educational purposes. Among other potentials for IT in science education it bears with it the possibility to create digital learning materials, simulating unobservable natural phenomena that can be made internationally available for students by means of the Internet. However, it must be emphasised that technologies like this have to be considered constituting just an ‘aid’ to teaching, because it is “uncertain whether, in any deep sense, the tasks of a teacher can be “handed over” to a computer, even the most “responsive” one that can be theoretically envisioned” (Bruner, 1996, p. 2)

Even though IT has been used for centuries and now is indispensable in most areas disseminating almost all societal and commercial activities the use of this technology for educational purposes in schools has remained low. There have been some attempts from companies and organisations with sanguine expectations to distribute digital learning materials to schools, but alas these applications have soon found a shrinking market and mostly ended up as not being used at all. Cuban (1986) found various explanations for teachers reluctance to make use of technology in classrooms. One important incentive, though, for teachers to employ a new technology in their teaching is that it can prove to be beneficial for their students learning. Hitherto the marketing of computerised educational applications have not been accompanied by research results guiding teachers in their use of this novel teaching aid. What Lagemann (2000) says about educational innovations in general, namely that it is “amazing to realise that publishers, test makers, and reformers of every kind and stripe can “sell” their wares without prior piloting or evaluation” (p. 238) seems to apply to IT in particular. The lack of research results informing teachers about students’ understanding of computerised learning applications in educational practices may therefore be one major factor distracting them from adopting this technology. It is in view of this, I see my studies of students’ understanding of computer animated learning material as a contribution to the knowledge of the technology as a teaching aid in science education.

Institutions governing the school system all over the world have realised the educational potential that IT bears with it and the need to establish the technology in schools. In the Swedish school system there has been several efforts made both by governmental and local institutions to stimulate and spread the use of IT in schools practices. A national programme, ITiS, was executed during a 3-year period between 1999 and 2001 with the aim of implementing computer technology in the Swedish educational system (Eriksson-Zetterquist, Hansson, Löfström, Ohlsson, & Selander, 2006). In the municipality of Gothenburg this venture was followed-up by Lust@IT, a project for inspiring and supporting teachers in IT related school activities.

Personally I have been involved as an instructor in both of these enterprises for implementing digital technology in schools. My engagement in these projects together with my interest in developing and renewing science education has led me to an interest in computerised applications as teaching aid.

Research and practice in the school system

In order make it possible for the school system to profit by research results produced by the academy there is a need for a closer connection between these institutions. Politicians and Governments thrust for 'evidence-based education' calls for teaching practice to be based on the best obtainable educational research results (Davies, 1999). The idea of teaching as an evidence based practice is, however, called into question by for example, Biesta (2007) who contends that education is "a thoroughly moral and political practice that requires continuous democratic contestation and deliberation" (p. 1). Notwithstanding, if viewed as an evidence-based practice or not all actors in the current school debate acknowledge the importance of communication between educational research and educational practice. This need of communicating and disseminating educational research results have, for example, been pronounced by editors of journals of research on technology in education:

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

This realisation of a close contact between research and practice in education has not always been evident in the school debate. Instead, the link between the practice of teaching and educational research has traditionally been very weak (Lagemann, 2000). Lagemann describes how, historically and theoretically, two diametrically contradicting positions can be discerned in attitudes towards the relation between teaching practice and the knowledge of the same. In the early nineteenth century the debate in the United States was, on the one hand represented by John Dewey's[1] democratic view on education and on the other hand by Edward Thorndike's[2] behaviouristic approach to educational practice. By defining teaching as merely a technical

[1] John Dewey (1859 – 1952), was an American philosopher, psychologist and educational reformer whose thoughts and ideas have been highly influential in the United States and around the world.
[2] Edward Lee Thorndike (1874 – 1949) was an American psychologist whose work about the learning process laid the scientific foundation for modern educational psychology.

task, Thorndike thought teachers should come to understand their subordinate role in the educational hierarchy. In line with this, Thorndike projected a model for the educational profession presuming "that the education researcher was the searcher for truth and the practitioner was merely the person concerned with application" (ibid, p. 61). In contrast to this hierarchical view on teaching Dewey (1916), in his social approach emphasised that it is the entire school sector including teachers, researchers and parents that shall participate in an intellectual debate developing the educational practice. I myself, endorsing a socio cultural view on learning, where knowledge is seen as built in interaction between humans in social practice, anticipate a development of the Swedish school system where the Deweyan democratic perspective on educational practice and research will be realised.

The close connection between practice and research that exists in some professions as for instance in medicine has not yet developed in education. Lagemann (2000) argues that "in part, this is because education is a field that draws on different disciplines, each of which has its own canons and conventions" (p. 240). Such a relationship can be beneficial to both the school system and the educational research community because "teaching is the central art of education" and "it involves knowledge and behaviours that can be studied and improved through research" (ibid., p. 242). Despite the fact that educational research and educational practice has existed as more or less two separate fields for a long time, it was not until 1999 that the Swedish parliamentary appointed committee, 'Lärarutbildningskommittén' gave recommendations[3] regarding the connection between teacher training programs, educational research and the possibility for working teachers to be enrolled in research education programs. This proposal clearly shows that the committee wishes a closer connection between teacher training and teaching practice as well as the desire to tie educational practice closer to educational research. The committee furthermore suggested that a new area of science; Educational Research (Utbildningsvetenskap) should be established. 'Educational Research' as a defined discipline has now been established at many universities including the University of Gothenburg where 'Centrum för utbildningsvetenskap och lärarforskning' (CUL) in September 2005 initiated a research school for practitioning teachers. I was privileged to be registered in the first group of PhD students participating in this research school. My anticipation is that the participants in this educational research school will function as a spearhead aimed both at the pedagogic research community and at the school practice in an attempt to bridge the cleft between these fields of activities in the educational system.

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

The research project

The prospect of using animated multimedia presentations for learning purposes has aroused a growing interest in the educational system and accordingly has generated a substantial amount of research results (e.g., ChanLin, 1998; Greiffenhagen & Watson, 2007; Mayer & Moreno, 2002; Rebetez, Bétrancourt, Sangin, & Dillenbourg, 2008; Schnotz & Rasch, 2005; Tversky, Morrison, & Betrancourt, 2002). Especially in subjects of science the educational potential for animation illustrating unobservable microscopic phenomena has attracted researchers' attention (e.g., Hennessey, et al., 2007; Kozma & Russell, 1997; Lowe, 2003; Roth, 2001; Roth, Woszczyna, & Smith, 1996).

Digital learning material can of course be studied from different epistemological and analytical perspectives. As my research interest lies in the situated use of digital learning material where the technology is used as an integrated part of an ordinary school activity involving collaborative problem solving and joint knowledge building; I will study the educational intervention from a socio cultural perspective (e.g., Säljö, 2000; Wells, 1999; Wertsch, 1991). This epistemological standpoint has consequences both for the methodological and the analytical approach that is applied in the studies. Studies of animated material for educational purposes have, hitherto, mainly been concerned with learning outcomes from large scale studies, producing quantitative data and results that do not account for individual variances in students' interpretations of a simulated concept in quantitative terms. Results emanating from such studies can generate information about what works and what does not work in certain situations but not about how students perceive the described events and reason in connection to the learning material. For the study of learners' joint knowledge building in connection with computer technology an in-depth analysis of students' interaction with each other and the interface is required (Lemke, 2006). Interactional studies as the ones presented in this thesis, will hopefully produce results that tell us about how learners construe information mediated by digital learning material and inform design and employment of animated learning material in school activities.

Due to the incapacity of our senses some events are not observable and we therefore have to construct illustrations to visualise concepts of these phenomena. It is on this abstract scientific level that animations of molecular processes can have the potential of raising students' awareness of the existence of unobservable phenomena. The digital learning material used in the reported studies deals with molecular processes that symbolise unobservable natural phenomena that we have to conceptualise on an abstract level. An assumption is therefore that animated learning material, visualising invisible scientific concepts, might function as a learning aid for understanding of abstract processes. As Bruner (1977) summarises his thoughts on aids to teaching:

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

Students' activity of understanding simulated scientific processes in digital learning material is interesting to study since it involves the construal and merging of such different semiotic resources as language and animated models of scientific concepts. In this process the learners have to make use of both their subject matter knowledge and their linguistic proficiency. As students, in normal school activities most often are required to give a written account of their understanding of the studied subject, their linguistic abilities are put to the test both in their interpretation of an instructional text and in the production of their own written account.

Research of digital learning material often produces results that are not so readily adopted by the school system and transformed into practical learning environments. One such problem of using research results for the teaching practice is that "several of the findings emanate from more or less experimental studies or short-term interventions, which have been hard to replicate in an everyday school practice" (Lantz-Andersson, 2009, p. 16). This concern for research undertaken in real school activities is also expressed by editors of journals of educational technology: "Much of the research in educational technology (and in the field of education as a whole) has not been directly connected to schools or related to learning outcomes" (Schrum, et al., 2005, p. 204). The editors furthermore assure that they "seek authentic research in authentic learning situations and recognize that research in these settings involves a number of complex design decisions and compromises" (p. 204). By this statement the editors acknowledge the problem of conducting research in classroom context that are "messy and complex" (p. 204) but also announce the need of encouraging research in actual school practice. Accordingly, research undertaken in authentic school settings might produce results that are more relevant for school activities. Hence, if research findings should have any relevance for implementation and employment of technological devices for school practice, it has to be tested in just that environment. In my point of view, no educational device can stand on its own and be investigated in isolation from the environment where it is intended to be used, animated software as every teaching aid has to be studied in its actual setting in order to be appropriately assessed for educational purposes. As this study is guided by a research interest in how animated software is made use of in authentic school settings I believe a more in-depth study of learners' understanding of animated software will give additional and valuable contributions to the knowledge of computer animations in science education. Thus, as my research has a practical endeavour, I consider it important to study how computer animated software is understood and made use of in a natural educational setting.

The concept of 'authentic learning' is by Schrum, et al. (2005) applied to designate learning situations that take place in natural school activities. Conversely, the notion of 'authenticity' in education has by Petraglia (1998) been described as to "bring authentic learning materials and environments into the classroom" (p. 5). However, in a socio cultural perspective, espoused in this thesis, learning is seen as a situated activity occurring in every situation where people engage in activities (Lave & Wenger, 1991). Hence, learning accruing from institutionalised education in classrooms is viewed here as 'authentic' in the same sense as learning taking place in all learning situations.

With this organisation and research agenda applied in this project –results from the first study were discussed with the teachers and were used to improve the design and enactment of the practices in the second study –it can in some respect be characterised as a design experiment (e.g., Brown, 1992). The Design-Based Research Collective (2003) maintains that this kind of research can create and extend knowledge about developing, enacting, and sustaining innovative learning environments. In design-based research the main emphasis is on how design functions in authentic school settings where "it must not only document success or failure but also focus on interactions that refine our understanding of the learning issues involved" and "relies on methods that can document and connect processes of enactment to outcomes of interest" (ibid., p. 5). Furthermore, one cannot expect immediate pay-offs from a technical innovation; new technologies have to be refined and appropriated to be able to compete against tried-out and reliable practices (Bereiter, 2002). Design research is therefore a prerequisite for "sustained innovation, which realizes the full potential of an innovation and overcomes its original defects and limitations" (ibid., p. 321). Bereiter also states that "sustained innovate development" as a purpose of design research (p. 326) makes it possible for educational technologies like computer simulations to survive their first failures and be driven by their potential as a learning device.

Aim and research questions

The overall aim is to study students' practical problems of comprehending computerised learning material. The studies are conducted in natural educational settings with a focus on how activities with the digital learning material appear from a student perspective. Results from the studies will contribute to the understanding of how learners make use of digital material involving several semiotic resources in a school context.

The learning material employed for this study, describes dynamic scientific concepts both in text and by animated displays. Such an explanation of phenomena involves reading of two different semiotic resources, i.e., linguistic and visual, and the merging of these resources into a joint description of the events by the learners. Two empirical studies provide detailed analyses of students' interaction when working collaboratively with the task of understanding and making an account of biochemical processes described in animated learning material. The analytical focus is on how task formulation, technology, language and school norms direct students' achievement of a joint description of the illustrated events. An underlying assumption behind my project is that animated displays might have a potential to facilitate students conceptualising of invisible phenomena.

Research questions that have guided the study are:

How do students make use of the digital learning material and talk about the animated events?

What kind of relations can be found between the animated digital learning material and students' joint reasoning about the scientific phenomena?

How do students frame their task of grammatically re-presenting what is happening in the described events by means of the animated illustrations and the instructional text?

In what way does the formulation of the task direct the students' understanding of how to approach and accomplish their assignment?

Overview of thesis

The first section consists of a cover paper based on two successive articles that are appended in the second part of the thesis.

In this first introductory chapter the field, topic and aim of the research have briefly been presented. The next chapter presents the background for the study and previous research in the field. Chapter three gives an outlook of perspectives on learning and knowledge and concludes with epistemological considerations underlying this thesis. Chapter four accounts for the analytical approach and methods applied in the analysis of the empirical material presented in the two articles. In chapter five a summary of the two articles is presented. The final chapter discusses consequences for design of software and educational framing from a didactical perspective and ends with some concluding remarks about use of animated learning material in science education.

The second section of the thesis presents the following two empirical studies:

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

II) Karlsson. G. (accepted for publication). Animation and grammar in science education: Learners' construal of animated educational software. *International Journal of Computer-Supported Collaborative Learning*.

Background

Implementing new media for education and learning has always been accompanied by great expectations (e.g., Cuban, 1986). This is in particular true for the introduction of computer technology in schools. The vision for use of such technology has been bright and the benefits almost taken for granted. Large sums of money have been spent by The Swedish government on several projects aimed at stimulating the use of computer technology for educational purposes (for a research review see, Riis, 2000). Efforts were primarily made on providing classrooms with computers but without any profound direction given for how and for what purpose computers would be used in education. The rationale for computerising schools, at the onset of the 1980's was a somewhat vague idea about that students must be prepared for the labour market (Riis & Jedeskog, 1997). The call for computers in schools came primarily from the authorities rather than from practitioning educators and critical views on the computerising of learning and school activities were much ignored (Karlsohn, 2009). Also, applications for educational use were few and most teachers could not see how computers would benefit students' learning. Consequently, many of the computers installed in Swedish schools became dust-collectors and much of the money spent did not fulfil its purpose (Riis & Jedeskog, 1997).

During this nearly three decades since the introduction of computers in schools, the technique has developed and thus the opportunities for the school system to make use of more advanced applications. In a research report published by the Knowledge Foundation (KK-stiftelsen, 2006), it is claimed that there has been a strong and positive increase in the use of IT in the Swedish school system from the end of the 1990's to 2006, however, with a break in the upward trend from 2003. The report states that over 70 % of the students in secondary school declared that they used computers in the classroom at least once in a week.

From my perspective it is not so much the frequency of IT use in schools that we should focus our interest on but rather, in what kind of educational activities the technology is applied. The importance of focusing on the pedagogical appliance of IT is also recognised by the International Society for Education (ISTE) in their comprehensive report on technology and educational change in a global perspective where it is concluded that:

> "We show that ICT use is embedded in patterned sets of pedagogical practice. The "dependent variable" should not be the extent of use of ICT or even the kinds of ICT used. Rather it should be the particular sets of patterns of pedagogical practice and ICT use considered together." (Kozma, 2003, p. 237)

This statement should, however, be evident since school education is primarily about learning a subject and not about making use of technology as such. The use of IT in schools seems so far primarily to have been exploited for procedural purposes. Eriksson-Zetterquist, et al. (2006) found, in a study in five Swedish municipalities, that IT as a school activity was primarily applied for writing texts, information retrieval and communication whereas computer applications integrated in the curriculum as resources for learning, subject matter knowledge were found to be scarcely utilised. Reasons for this were found to be difficulties of finding appropriate applications but also that teacher of specialist subjects are not prepared to change their pedagogical ideas to meet the conditions of IT in education (ibid., p. 185).

Multimedia in science education

The digital revolution has eventually brought about the combined use of several media for example, text, audio, still images, animation and video. Such 'multimedia' applications are now seen as a major resource for schools when introducing ICT in their learning activities. The emphasis on multimedia as a teaching aid in the Swedish school system can be seen in the naming of the branch of the National Agency for Education (Skolverket) responsible for the pursuit of a net based national resource centre for teaching media such as, ‘The Multimedia Bureau’ (Multimediabyrån) [4]. This public authority provides teachers in the Swedish school system with web-based and free educational resources on how to make use of multimedia for school activities.

In the field of science education the Internet gives access to some free web sites integrating technologies with pedagogy into specially designed learning environments. One example of such a learning platform is the WISE-project[5] founded by the University of California, Berkeley which offers multimedia learning applications dealing with curriculum topics in science and environmental subjects. The Norwegian government supported project Viten[6] is developed from the same learning platform and provides a web-based platform with digital learning resources in science for secondary school students. Additional examples of free and on-line interactive media, integrated in the science curriculum are the Bio-HOPE[7] project for environmental science investigation and the Virtual Labs[8]; both transatlantic cooperation projects between Swedish universities and the Stanford University of California, financed by the Wallenberg Global Learning Network.

There are few commercial sites offering interactive educational software, and besides, these attempts tend to be of short duration. One such company, ‘VETA Lärospel’ capitalising the gaming culture for educational purposes and funded by millions of Swedish crowns founded by influential organisations had to finish their business due to insufficient demand for its products. This example may be an indication of how commercial products like this are received by the school system. It is however, an open question as to what extent on-line resources, free of charge, like the ones previously mentioned are utilised by the education system.

Notwithstanding, if financed or commercial, what all these projects, distributing multimedia material, seem to have in common is the scarcity of research results explaining how these applications function as learning aids. As Mayer (1997) concludes for the prospects of computer-based educational material: “In computer-based multimedia learning environments students have the opportunity to work easily with both visual and verbal representa-

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[4] Presentation at: http://www.skolverket.se/sb/d/2366/a/13071
[5] The web-based learning science environment is described by (Slotta, 2002) and is available at: http://wise.berkeley.edu
[6] Available at: http://ny.viten.no/
[7] Available at: http://esi.stanford.edu/
[8] Available at: http://virtuallabs.stanford.edu/

tions of complex systems, but to fruitfully develop these potential educational opportunities, research is needed in how people learn with multimedia" (p. 17).

This said, it should also be emphasised that it is important not to rise to great expectation in technology as a sole pedagogical saviour (Säljö & Linderoth, 2002). By scrutinising the relation between activities and actions performed by students learning from educational technologies Ivarsson (2004) concludes that, "Given any educational material, representational technologies or otherwise, we cannot *take for granted* that pupils/students will approach them in the manner intended" (p. 46). Educational gains from technical innovations, thus, cannot be presupposed and it is therefore crucial that new technological learning materials are researched before being praised and advocated for implementation.

Considering animations in education Mayer and Moreno (2002) recommend that we instead of asking "does animation improve learning?" we should ask "when and how does animation affect learning?" (p. 88). The authors contend that animation is a potentially powerful tool for multimedia designers and they also provide research based examples of ways in which animation can be used to promote learner understanding. However bright their prospects for multimedia use in education they also observe that:

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

For computer animation to become a powerful learning device and support knowledge construction Mikropoulos, Katsikis, Nikolou and Tsakalis (2003) suggest that the software has to involve specific didactic goals, integrated educational scenarios, metaphors with pedagogical meaning and include didactic and learning outcomes.

Representing microscopic events

Models of unobservable scientific phenomena, representing structures and dynamic characters for educational purposes can be shaped in varying ways. Educators have traditionally tackled the problems for students to conceptualise processes that involve gaseous forms by representing molecules and their circulation with pictorial models supplied with arrows. So, for example, teachers draw sketches on whiteboards to exemplify their lectures and textbooks are equipped with chemical symbols illustrating the described phenomena. Hence, static pictures render it possible to present specific spatial configurations and indicate directions of activities but provide no information about the course of events. In all static models the learners have to envision the dynamics in the processes by themselves. Han and Roth (2006) identified several problems with students' understanding of models illustrating gaseous states in textbooks. One such problem is, for example, that whereas the main text expresses the movement of a molecule an associated static image cannot show this movement. Another consequence of static illustrations is that gases are described as motionless molecules of matter evenly distributed in an empty space.

Molecules and atoms cannot be observed ocularly, not even with a microscope; although such unobservable phenomena are referred to as microscopic. Biochemistry makes use of various symbolic representations for illustrating unobservable abstract events. Representations of invisible elements are for example, symbolised by letters or conventionalised pictures and various models are used alternately depending on context and its purpose. For educational purposes, there are models specially adapted to aid teaching and understanding of scientific concepts (Chittleborougha, Treagusta, Mamialab, & Mocerinoa, 2005). Such models, originally used for scientific purposes are commonly applied as instructional tools in science education; although in a somewhat adjusted form. There seems, however, to be a gap between how expert scientists and students construe these symbolic representations. It has been observed that students perceive models in different ways compared to those with a scientific background (Roth, McRobbie, Lucas, & Boutonné, 1997; Snir, Smith, & Raz, 2003). Kozma and Russell (1997) found that surface features of chemical representations is attended to by both novices and experts but the difference though, is that while professionals focus on underlying concepts the learners seem to be constrained by the salient characters of the display. This implies that professionals and learners might not see the same thing in an animated display of a phenomenon. Grosslight, Unger, Jay and Smith (1991) argues that students are "more likely to think of models as physical copies of reality that embody different spatiotemporal perspectives than as constructed representations that may embody different theoretical perspectives" (p. 799). Learners, lacking the necessary subject knowledge may therefore construct unintended conceptions that are not those of canonical science. As remarked by Snir, et al.(2003):

> Even though the particles of matter cannot be seen or touched at a macroscopic level, scientists assume that these particles exist and they become an important reality for their mind. In so doing, the science expert relates to an unseen conceptual level that is very much at odds with surface appearances. In contrast, the novice relates either to the concrete world of objects

> themselves or to a conceptual level that corresponds more directly to surface appearances (e.g., matter is continuous because it looks continuous). (p. 796)

These observations draw attention to the problem of students' accomplishment of conveying representations of invisible scientific concepts into for them intelligible constructions. Students' interpretation of a demonstrated scientific phenomenon is not a straightforward and unambiguous quest but emerges from intertwining activities and interactions both with the social and material world and often do not correspond with what is intended by the educator (e.g., Roth, et al., 1997). "Even students' perceptions of carefully staged teacher demonstrations are radically different and a function of prior expectations". (Roth, 2001, p. 50) Studying learning from computer software Roth and Lee (2006) contend "that knowing about the aspect of the world, about the variables pupils investigate in school science requires learners to ontologically ground this experience of the material/social world first before they can begin making any sense of it" (p. 345).

Learning from visual representations involves interpretation of a macroscopic and a microscopic world and the relationship between these dimensions as well as linking an explaining text to the visualised phenomenon (Han & Roth, 2006). Students are also required to attend to some characteristics of the display but not to others and understand "how the gratuitous details are eliminated" (ibid., p. 178). The process of construing visualised phenomena has to include the learner's active perception and interpretation of the depicted representation (ibid.). Consequently, making meaning out of an illustration implies that the interpreter draws on individual experiences and preconceptions. This also means that the interpretation of an illustrated phenomenon differs from reader to reader (Han & Roth, 2006; Lemke, 2006). Studies of students' efforts in interpreting static images in textbooks, attempting to transmit scientific ideas and to integrate them with the text, have revealed that it is not a trivial task and requires work to be done by the learners and demands the teachers' attention to their students' difficulties (Ametller & Pint´o, 2002; Stylianidou, Ormerod, & Ogborn, 2002).

Animated representations as models

The use of 3 D animations enables new ways of representing scientific phenomena that can otherwise only be indirectly demonstrated with, for example, experiments. By means of the digital technology we are able to create animations that visualise molecular processes and make the 'unobservable observable'. Animated pictures in contrast to static illustration render it possible to convey information about both spatial and temporal structures by visualising dynamic characteristics of the depicted phenomena. Hence, from an educational point of view there could be benefits from dynamical visualisation of invisible gas states in biochemical processes.

Like all educational tools computer based 3D animation brings with it certain problems. One problematic consequence of animations used for educational purposes is that interpretation of the depicted phenomena seems to be highly dependent on the learners' preconceptions. In a study of how students learnt to explain computer-animated events, Roth (2001) showed that animated episodes can be interpreted in multiple ways and therefore do not embed unambiguous meanings: "What and how entities are salient is therefore an empirical matter" (p. 45). Krange and Ludvigsen (2008) contend that, not having access to the specific knowledge domain where only a small part is illustrated in the media "means that the students only get access to the top of the iceberg of this knowledge base, and what part of this that they manage to realise in practise is an empirical question" (p. 29).

In studies of how meteorological novices worked with animated weather maps Lowe (1999, 2003, 2004) found that much of the information extracted is driven by the objects observability and by dynamic effects rather then what is thematically relevant. Retention was also higher for those aspects of the dynamic graphics that were relatively easily extracted. Lowe (1999) also revealed that lack of appropriate background knowledge of the animated phenomenon led students to impose an improper simple everyday cause–effect interpretation of the display. By allocating features in the display to 'subject' and 'object' roles they tended to fall back on their everyday knowledge of a straightforward view of causality (ibid.). Lowe (2003) argues that students' "predisposition to search for cause–effect relations that seem to make the material more 'meaningful" raises the "possibility that misconceptions can actually be induced when learners work with instructional animation" (p. 174). In consideration of several studies of animations as representational tools Säljö (2004) concludes that.

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

An additional hazardous consequence of using visualised models as representations is students' and even teachers' tendency to take visualised symbols as references in their talking about the scientific concepts (Krange & Ludvigsen, 2008). In their study of secondary school students' joint interpretation of molecular models in a computer-based 3 D model supported by a website Krange and Ludvigsen found that the students together with their teachers used everyday concepts and "labelled, for example, the amino acids as balls" (p. 45). This "means that they mix their everyday language with more scientific concepts" (ibid., p. 45). Krange and Ludvigsen also found that a procedural type of problem solving tended to dominate the students' interactions, while conceptual understanding of the model only were present when it was necessary to work out the problem. The authors conclude that this tendency of making the understanding of the knowledge domain secondary to solving the problem present particular challenges to make the conceptual knowledge construction explicit in the educational environment. The use of 3 D models in a school context, thus, entails certain kinds of challenges linked to the institutional practice "to secure that the students actually solve problems that are predefined in the syllabus list" (ibid., p. 25).

Animation as teaching aid

Animation, visualising biochemical processes, can be positioned into the broader classification of computer simulations defined as: "programs that contain a model of a system (natural or artificial, e.g., equipment), or a process" (de Jong & van Joolingen, 1998, p. 180). A general assumption is that animations enhance learning and should be the preferred mode for presenting graphics of dynamic processes (e.g., Schrum, et al., 2005). With an animated display it is also presumed that we can rectify some of the above-mentioned problems associated with the use of static images for illustrating a scientific concept. Gabel (1998) argues that technology particularly offers the possibility to help students visualise motion and structure of molecules. Computer animated events also have the capacity to make the interface a tool for exploring micro worlds (Roth, 2001).

Research results, up until now, have however, not been able to show any consistent enhanced learning outcome brought about by use of animations compared to static illustrations. In a comprehensive research review of animations for educational practice, Tversky, Morrison and Betrancourt (2002) could not find evidence supporting the view that animations are superior to the use of static graphics for learning. The results are inconsistent and display a complex and confusing array of outcomes, depending on educational setting. Quite contrary to the general belief in the benefits of animations Mayer, Hegarty, Mayer and Campbell (2005) found support for a 'static-media hypothesis' in which they declare that "static media (such as static diagrams and printed text) offer cognitive processing affordances that lead to better learning (as measured by tests of retention and transfer) compared with dynamic media (such as animation and narration)" (p. 256). This hypothesis was tested in an experiment where groups of students learned about how physical and mechanical processes worked. Students receiving computer-based animation and narration were compared with groups given a lesson consisting of paper-based static diagrams and text. On a subsequent retention and transfer measure the paper group performed significantly better than the computer group. The authors contend that this result gives no support for the superiority of dynamic media and that there is instead support for the static media hypothesis. On the contrary, they remark that overall their research "should not be taken to controvert the value of animation as an instructional aid to learning" and it is suggested that "animations may be more effective when used to visualize processes that are not visible in the real world" (ibid., p. 264).

On the other hand, there are studies demonstrating that animations may have advantages over static illustrations for certain kind of learners and learning situations. ChanLin (1998), compared how different visual treatments such as, no graphics, still graphics and animated graphics influenced learning for students with different prior knowledge levels. It was found that animated graphics served as a better device for experienced learners but not for novices. The author claims that the study supports the assumption that students with different prior knowledge learn visual information differently and therefore require different presentation forms for achieving learning goals. When comparing individual learners with students working co-operatively Schnotz, Böckheler, & Grzondziel (1999) found that animated pictures resulted in better learning for individual learners but lead to lower results for co-operative learning. Conflicting results have, however, been presented by Rebetez, Bétrancourt, Sangin, and Dillenbourg (2008) who reported that learning scores were higher for students working in dyads than for individuals studying the same animated graphics. Thus, the two studies, referred to above, came to contradicting results when comparing students working individually with students working in pairs, exploring computer animations. Regarding these conflicting results, one have to consider the different possibilities the student had to control the pace of the animations in the two studies. In the study by Schnotz et al. (1999) the interactive animated pictures gave learners the opportunity to replay and scrutinise the animated event while the participants in the study by Rebetez et al. (2008) had no control over the presentation. The lack of significant results confirming enhanced learning by animations is, however, not a sole characteristic of animations but seems to be applicable to all technology-based learning tools (for a discussion about this issue see, Russell, 1999, p. 18).

To summarise, animations depicting unobservable scientific phenomena provide opportunities that static pictures do not but besides bring with it complications when used for educational purposes. The contradicting research results reported above suggests that providing a truthful animated depiction of the to-be-learned material may not in itself be sufficient to produce the desired outcome. It also calls into question "a simplistic assumption that animation is intrinsically superior to static presentation" (Lowe, 2003, p. 175). The inconsistency in research results concerning the advantages of animations in education illustrates the complexity of learning from representational media where varying aspects as the learners' preknowledge and the educational setting have to be taken in consideration. Despite the uncertain results regarding animations supremacy over static pictures in education, expectations of the technology remains high. This situation calls for further research in the area of animated learning material for educational purposes in order to overcome unintended complications and make the best use this learning aid.

Animated learning material in school activities

For the use in school the computer technology offers a considerable promise in the respect that "they can furnish flexible representations that may become the objects of joint reference for learners" (Crook, 1994, p. 228). However, regardless of how sophisticated this representations become, there is always an individual interpreting the depicted phenomena based on her/his own experiences and, hence, there will always be grounds for unintended interpretations (e.g., Han & Roth, 2006; Lemke, 2006; Roth, 2001; Roth, et al., 1997). As mentioned earlier, students' interpretation of an animated display is never a given and therefore always has to be supported by other educational means (e.g., Krange & Ludvigsen, 2008). It is therefore important to consider a wider learning activity when applying animations in teaching. Recommended ways to exploit animations in educational settings have been through activities that generate explanations or by answering questions during learning (Mayer, et al., 2005). For integrating and making the best use of animations in science education Hennessey et al. (2007) propose instructional guidance, either written or narrative. They contend that success of technology-integrated science teaching "relies on teachers exploiting the dynamic visual representation through using the technology as a powerful, manipulable object of joint reference" (p. 149) where the shared experiences can be used to stimulate discussions and generate hypotheses.

Thus, it is necessary to consider all factors comprised in handling the knowledge domain when studying implementation of animations as a learning aid. This involves actions such as introduction of the subject and formulation of assignments given to the students in connection to their work with the animations. It is in this research domain I see the importance of studies for an understanding of how this technology is used in practice.

Scientific reasoning

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

Seeing as a multimodal phenomenon

Noticing and explicating the "seen but unnoticed"[9] details and interpreting what is seen *in situ* can be said to be the practice of seeing from the analyst perspective. When analysing the participants' interactional accomplishment of meaning making of events on a computer screen one have to attend to the interlocutors' multimodal actions in their attempts to achieve a shared understanding. The problem of characterising the concept of 'understanding' and 'seeing' can be can be illustrated with the saying 'I see' which in fact means 'I understand'. In everyday speech we often equal 'to see' something with 'understanding' the same thing but we have to problematise the concept of 'seeing'. According to Gibson (1979) our visual perception provides us with information of the 'affordances'[10] of observed surface objects. 'Affordance' is in sense physical objects but at the same time psychical and it "points both ways, to the environment and to the observer" (ibid., p. 129).

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

[10] The concept of 'affordance' denotes what the environment offers the organism "what it *provides* or *furnishes* either for good or ill" (Gibson, 1979, p. 127).

Hence, in this ecological approach to visual perception individuals perceive the affordances of their environment as a consequence of their previous experiences.

'Seeing' as an organized phenomenon through the precise and fine coordination of the participants' conduct was demonstrated with video recorded material by Nishizaka (2000). In two such distinctly dissimilar activities as joint playing of a computer game and a lesson with a learner and an instructor in front of a computer screen, it was shown how the participants organized their seeing activity interactively and sequentially. Nishizaka (2000) argues that, "seeing is a public and normative phenomenon, which is achieved in and through the actual course of a distinct activity" (p. 120). The study also demonstrates that an activity is structured in various ways in which the participants display and direct their actions in their effort to accomplish a task. Objects on the monitor had its visibility embodied in the actual arrangement of participants' bodies and conduct in an ongoing activity. Therefore, analysts should not presuppose that there are human beings on the one hand and artefacts on the other and try to explore the interactions on these entities; instead objects together with human bodies, artefacts, talk and other conduct constitute an activity system (ibid.). Nishizaka concludes that: "Seeing is not a processing of information that comes from objects in the outer world into the human body, but a structural feature of an activity system" (p. 122).

Different practices of seeing as "professional vision" and "instructed vision" was demonstrated in surgical work by Mondada (2003). In her study, laparoscopic surgery with video recordings of the surgical work was both transmitted to screens for the operating team and to a distant audience looking at the pictures for instructional purposes. It was revealed how an utterance as, 'you see' by the surgeon prefaced the accomplishment of the visibility for the audience during the demonstration and thus accounted for a kind of 'instructed vision.' This 'instructed vision' orchestrated by the descriptive and pointing activities of the demonstrating surgeon involved more movements in the camera work. On the other hand 'professional vision' for the purpose of the operating team demanded a more stable camera view. Mondada argues that these differing practices of 'seeing' involving coordinated actions, gestures, talk-in-interaction and image manipulation, facilitate the 'professional vision' of the surgeon as well as it develops an 'instructed vision' for the audience.

In another study focusing on multimodal resources by which participants make their orientations publicly visible to each other, Mondada (2006) demonstrated the ways in which these resources can be documented in an analysis. It was done by approaching the phenomenon of the practices by which participants' 'projects the end of the turn and the closing of the sequence'[11]. The studied video fragments were taken from a meeting in an architect's office with three people working on a building project. The analysis focused on the participants' problems in producing the recognizable nature of their actions. As an example of this, it is shown how one of the participants tries three times to initiate the closing of an actual activity phase but is blocked each time in his projection of another participant. This is made visible not just by the sequential organization of talk-in-interaction but also by the organization of the local space populated with artefacts and configured by the participants' gestures and body movements. This problem of documenting the recognizable nature in the participants' actions is also the problem for the analysts. The analysis of mutual orientations depends crucially on the kind of data the analyst is able to produce and on the way in which temporality and deployment of actions are transcribed and represented.

The video data analysed in the study cited above, was recorded with four cameras, making available for analysis both the participants' gestures and their orientation to these gestures. The data was represented in a combined form of a linear transcript and a second time line to which various actions, both verbal and gestural, were referred to. Mondada argues that this various perspective of representing video recordings "all contribute to produce the intelligibility of the data for the analyst and the audience" (ibid., p.128). This statement also brings up the issue of re-presenting video sequences which will be discussed in the chapter 'Analytical approach'.

Expressing visualised events linguistically

An ordinary way of organising science education is that students, at the end of a learning activity, are required to give a written account of what they have learnt. This written explanation, either produced as a shorter report of what is learnt from some kind of demonstration or a more comprehensive account of a knowledge area given in a test is normally assessed by the teacher. As described earlier, the teacher draws on different experiences than the students when judging such a written account and often lacks insight in the learner's construal of the subject. Making a written report of events described in multimedia presentations requires students' interpreta-

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[11] A model for turn-taking in conversation is proposed by Sacks, Schegloff, and Jefferson (1974) which is characterised by locally managed, interactively controlled and sensitive to recipients design; allowing the recipient to predict points of possible completion where a unit is likely to end.

tions of several semiotic resources and then syntheses the information linguistically. Another complication for the students is that the school system requires them to express themselves in a school discourse at the same time that they are supposed to use their own words when they are describing a demonstrated scientific phenomenon and not copy written information.

Studying how animated events are described linguistically in a school context therefore requires a close inspection of the processes involved in how we grammatically construct descriptions of events. When transforming an experience into a linguistic expression, this transformation is necessarily structured by the grammar of our language (Halliday, 2004). Halliday contend that “understanding and knowledge are semiotic processes” (p. 11). Hence, our meaning making and understanding of events are affected by grammatical rules of the language. Scientific language is a special genre and constitutes a particular way of talking about the world (Lemke, 1990). Special features of scientific language are its preference in grammar for “using passive voice” and “abstract nouns derived from verbs instead of the verbs themselves” (ibid., p. 130). This way of describing events in nature in passive form and to use nouns instead of verbs is not what students are used to, which may result in students finding science hard to understand and refrain from the subject matter (ibid.). When describing linguistically an event, learners face the problem of grammatically constructing sentences of what is happening. “The sentence in its basic structure consists of a verb and one or more noun phrases.” (Fillmore, 1968, p. 21) The problem of lexical selection of verbs and nouns for insertion in a sentence depends grammatically on so-called ‘frame features’ into which a given verb may be inserted (ibid.). In a dynamic event some component is ‘attentionally detected’ which grammatically “maps just that parameter into syntactic subject” (Tomlin, 1997, p. 172). Tomlin therefore recommend that, when we study how conceptual representations of visual events are mapped into language, we should start by looking at the ‘attentional focus’ of the observers.

Choice of topic

The circulation of matter in the carbon cycle has been selected as the subject for the study. Three reasons have motivated this choice. The first motive is that it represents one of the main curriculum goals in the steering documents from ‘The Swedish National Agency for Education’ (Skolverket)12 for both science and social studies in compulsory school (grundskolan) and upper secondary school (gymnasieskolan). These steering documents emphasise the importance of students’ understanding of circulation of matter in the

[12] Skolverket, läroplaner. Available at http://www.skolverket.se

carbon cycle for the realisation of consequences of human activities for the impact of global warming and climate change.

The second reason for choosing this particular topic for my study is the students' difficulties in understanding processes involved in the carbon cycle. Despite its prominent position in curricula, a Swedish national evaluation report13 revealed low understanding of these biochemical processes for students in their ninth school year. So for example, only ten percent of the students were able to give an acceptable answer to the question about how a tree builds up its mass. The evaluation also investigated if there was any long-term advancement in students' understanding of the circulation of matter and compared results from tests carried out in 1992 and 2003 but no clear difference between these periods was demonstrated. To examine if there was any improvement of the results for students in upper secondary school (gymnasieskolan), compared with their ninth school year a follow-up study of the 1992 year result was conducted. This evaluation showed no general improvement of the students' understanding at secondary school level. The only enhancement detected was for students attending science and technical programs who showed limited higher results (Jansson, Andersson, & Emanuelsson, 1994). These low results for students' understanding of biochemical processes can be explained by the abstract nature of such phenomena. The assimilation of carbon dioxide in the photosynthesis involves transformation of matter from an invisible gas state to tangible objects, such as plants. Research results have clearly demonstrated students' difficulties in understanding the preservation of matter in phenomena involving the invisible gas state (e.g., Boz, 2006; Lofgren & Hellden, 2008; Stavy, 1988, 1990). Especially younger children seem to believe that matter only exists as long as it is visible (Stavy, 1990).

Obviously, the realisation of matter existing in the air is counterintuitive since matter is believed to have the ability be touched upon and have a weight and fall to the ground. Traditionally the problem of the awareness of matter existing as gaseous components in the air has demonstrated considerably scientific difficulties. It was not until the late eighteenth century when Antoine Lavoisier14 showed that substances can exist in a gaseous

13 Nationell utvärdering av grundskolan, Skolverket (2004). NU-03. Available at http://www.skolverket.se

[14] Antoine-Laurent de Lavoisier (1743–1794) was a French scientist prominent in chemistry and biology. Among his contributions to chemistry were the first version of the law of conservation of mass, the recognition and naming of oxygen and the understanding of combustion and respiration as caused by chemical reactions

form that the chemists realised the importance of these substances for combustion and respiration. Before Lavoisiers' scientific experiments showed that combustion and respiration was caused by chemical reactions with the part of the air he called 'oxygen', the prevailing view of combustion involved a weightless or nearly weightless substance known as phlogiston. This historically proven problem of realising matter as existing in the air and overcoming our everyday idea of air as a vacuum poses a genuine problem and a real challenge to be overcome in science education.

The third reason for choosing the carbon cycle as the topic for my research was the possibility of visualising the transitions between different molecular states by means of computer animation. This provides the possibility of enabling students to learn from a dynamic representation of invisible molecular gas states and study their understanding of such a representational form.

Design of the application

In preparation of this project, the selection of web based animations illustrating the circulation of matter in the carbon cycle was searched for on the internet. However, animations depicting biochemical phenomena in general or specific processes in the carbon cycle for educational use proved to be scarce. The few available resources were found to be either too complicated for school practice or mere conventional still pictures endowed with moving arrows, indicating a circulating process. Due to these difficulties of finding appropriate animated learning material for the purpose of my project an application specifically designed for the study was developed.

The production of the learning material started with the creation of 3 D animations in a 3ds Max® software. The animations were then rendered to video files that linked to the application that was made in html codes. The application was then published as a free and on-line homepage15. A more complete description of the structure of the application can be found in Study I.

Multimedia guidelines proposed by Mayer (1997) and Mayer and Moreno (2002) informed the design of the learning application. Based on a series of studies Mayer (1997) argues to have found consistent support that coordinated presentation of explanatory words and pictures is effective because it helps guide students' cognitive processes. Mayer also demonstrated that when such verbal and visual information is presented closely together, retention is augmented for the leaning subject. This he describe as the 'conti-

[15] Available at: http://www.init.ituniv.se/~gorkar/

guity effect' (p. 11). Mayer and Moreno (2002) in addition found support for a 'coherence principle' which means enhanced learning from a multimedia when extraneous words and animated structures are excluded.

In consideration of the findings presented above, the intention when designing the learning software was to furnish it with animations complemented with explanatory texts to facilitate for the student to get an understanding of what was happening in the animated processes. Each process within the carbon cycle was equipped with educational texts and accompanying pictures linking to animated sequences depicting the exchange of gas molecules between the organism and its surrounding. Just one process was visualised in every sequence with the ambition to make the illustrations as uncomplicated and concrete as possible. In accordance with the 'coherence principle' the animated sequences and the explanatory text were shaped to be as clear and concise as possible, excluding irrelevant words and structures. Thus, each page was captioned with an explanatory text and a miniature image underneath, linking to an animated sequence of the described process of photosynthesis, breathing, combustion and mouldering.

Another principle that Mayer and Moreno (2002) found support for was what they call the 'modality principle' which implies enhanced learning when animation is accompanied by spoken words rather than by on-screen text. The software was, however, not supplied with a spoken narrative due to two reasons. For one thing, sound included in the software presupposes that each computer, available in a classroom, is equipped with at least two headphones, which is rarely the case. Secondly, headphones would also, in case they would be accessible, infringe on the students' possibility to communicate within the group.

Theoretical framing

In this chapter I will give a background for the theory of knowledge and the epistemological considerations underlying my research project. Some of the most important issues in educational research have been epistemological i.e., how knowledge is constructed and learning is accomplished. Insights into these processes should in fact provide us with means to design education in ways that foster the intended learning outcome. The philosophical perspective on learning was, in the first part of the 20th century, dominated by a paradigm referred to as, 'behaviourism', mainly associated with the research of B.F. Skinner16. This physiological viewpoint is based on the assumption that all conducts performed by organisms (including humans)

[16] B. F Skinner (1904-1990) was an influential American psychologist.

for example: acting, thinking and sense can and should be regarded as behaviours. Accordingly, behaviourism purports to explain human and animal behaviour in terms of external physical stimuli and its responses. In the middle of the 20th century a more mentalistic view emerged in the study of human behaviours. Such approaches to theories of learning can be said to be represented by constructivistic and social constructivistic views of learning. From the end of the 20th century a socio cultural perspective of learning emerged where learning is assumed to take place when humans participate in cultural activities and where knowledge is embedded in activities where cultural and physical tools are integrated.

The socio cultural perspective on learning and knowledge

In consideration of views on the nature of human mind in the last decades, Bruner (1996) outlined two strikingly divergent concepts about the function of our mind and about how it might be cultivated and improved through education. The first of these two models is based on the hypothesis that our mind can be conceived of as a computational device. This 'computational' view is primarily concerned with 'information processing' where unambiguous information about the word is retrieved, managed and stored by a computational mechanism. "It takes information as its given, as something already settled in relation to some preexisting, rule-bound code that maps onto states of the world." (ibid., p. 1) Bruner, however, remarks that the process of learning and knowing "is often messier, more fraught with ambiguity than such a view allows" (ibid., p. 2). He also concludes that the human intellect is not independent of our culture and accessible devices, "for in certain respects, "how the mind works" is itself dependent on the tools at its disposal" (ibid., p. 2). This statement connects directly to the second approach to the nature of human mind which Bruner labels as 'culturalism'.

Culturalism takes its stance in the evolutionary fact that the hominid mind is linked to the development of the human culture. The culture is represented by a symbolism shared by members of a community, elaborated on and passed on to succeeding generations. This symbolic mode, although shared by members of the culture, shapes in the minds of the individuals: "its individual expression inheres in *meaning making*, assigning meanings to things in different settings on particular occasions" (ibid., p. 3). Consequently, it is our culture with its possibilities of inventing, creating, tool-using and communication that creates the foundation for developing and maintaining knowledge. Bruner does not reject the 'information processing' theory although he questions whether it offers an adequate enough observation of how our mind works and concludes that, "Culture, though itself man-made, both forms and makes possible the workings of a distinctively human mind.

In this view "learning and thinking are always *situated* in a cultural setting and always dependent upon the utilization of cultural resources" (ibid., p. 4). The concept of 'situated cognition' imply that "cognition, including thinking, knowing, and learning, can be considered as a relation involving an agent in a situation, rather than as an activity in an individual's mind" (Greeno, 1989, p. 135). This way of situating meaning making processes in its cultural context connects to the epistemological social cultural approach where learning and knowledge are mediated by tools and situated in a social practice (e.g., Säljö, 1998; Wertsch, 1991).

Presenting five case studies of activities where concrete forms of apprenticeship were characterised, Lave and Wenger (1991) formulated a theory about how learning and knowing is situated in social interactions when we engage in mutual activities. Learning is here viewed as a social situated activity where the learner gradually acquires knowledge and skill through engagement in an activity. This is achieved because the learner, at first, takes a peripheral role and then performs more advanced actions and finally acts as a knowledgeable and skilled person. Accordingly, the learner as a newcomer by this shifting location moves centripetally to eventually become a full practitioner. Learning in this view, characterised as a situated activity, is a process that the authors label as: *legitimate peripheral participation* (LPP). By this approach Lave and Wenger wanted to "draw attention to the point that learners inevitably participate in communities of practitioners and that the mastery of knowledge and skill requires newcomers to move toward full participation in the socio-cultural practices of community" (p. 29). As learning occurs through 'centripetal participation' in the community and knowledge is situated within the 'community of practice' learning and knowledge is distributed among the co-participants and not a one person act. Hence, understanding and knowing is considered to represent the ability to participate in social activities rather than performing individual mental operations. LPP occurs all the time and wherever a person engages in activities and is not restricted to apprentice-like situations. Seen from this perspective, learning is fundamentally distinguished from intentional instruction, which is so often used in educational practise. Consequently, LPP is not an educational form or a teaching technique but an analytical perspective and a way of understanding learning. Anyhow, Lave and Wenger proposed that studying and analysing schooling from the perspective of LPP "will turn out to be a fruitful exercise" (p. 41). Such an analysis will raise questions about relations of school practice and its knowledge production to the community at large.

Since the socio-cultural perspective on learning is just gaining ground in the educational debate and considering the fact that educational method in schools, and especially in science education, is still mainly based on constructivistic views on learning; I will in the following paragraph give a brief overview of that epistemological field.

Constructivistic views on learning and knowledge

In its emphasis on meaning making 'constructivism' differs clearly from the 'behaviouristic' concentration on observable responses to stimuli. The constructivistic approach to knowledge-building is often associated with Piaget[17] who showed that children in different stages of their childhood differed in relation to adults in their way of reasoning about phenomena that surrounds them.

With a standpoint in Piaget's cognitive developmental theory von Glasersfeld (1995) formulated four fundamental principles for a *radical constructivism*: (*i*) knowledge is not passively received either through our senses or by ways of communication; (*ii*) knowledge is actively built up by the cognizing subject; (*iii*) the function of cognition is adaptive, in the biological sense of the term, tending towards fit or viability; (*iv*) cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality (p. 51). Von Glasersfeld emphasises that radical constructivism is a thoroughly instrumentalist theory that rejects any metaphysical claim. He declares that the concepts we create to describe, for example, time, space and reality are just instruments that we use to organise our experiences but cannot be said to represent an ontological reality. An existing real world is neither presupposed nor denied but since the only picture we can obtain of the world is created in our mind, through our senses it is only this picture we can study. The theory implies that we cannot gain real knowledge about the world as it objectively appears since the only means we have to observe the world is though our senses. Radical constructivism is therefore not about what really exists or not but about how we build up our conceptual structures.

Von Glasersfeld emphasises that the concepts we use are made up of re-presentations where the hyphen implies the re-creation of our experiences. With these re-presentations we create concepts that represent a reality that we can re-create in our memories and refer to in our communication with other humans.

> "This ability to re-present objects to oneself is linked to language acquisition also in a very direct way. As long as words are used with immediate

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[17] J. Piaget (1886-1980) was a Swiss biologist and developmental psychologist concentrating on studies of children's development of thoughts and concepts during their childhood and adolescence.

> reference to the situation in which they are uttered, the speaker will be satisfied that the receiver has 'understood' the utterance, if the receiver's reaction is compatible with the speaker's expectation." (von Glasersfeld, p. 60)

Hence, humans' ability to express themselves linguistically provides an opportunity to study conceptualisation. Conceptual knowledge is expressed in symbols, mostly linguistic and therefore "semantic analysis of meaning has to be an important facet of any theory of knowing" (ibid., p. 76). When communicating linguistically the speakers have to assume that the concept a word brings forth is apprehended in a similar way by other users and the "assumption of such parallelism is the foundation of what is commonly called 'communication' " (ibid., p. 98).

When constructing knowledge, the language plays a significant role in that it enables us to construct knowledge of what we have not yet experienced. Each individual constructs their own knowledge models that give words and concepts its meaning. These meanings are modified successively when they are used in social interaction. According to von Glasersfeld the meaning of a concept can never be said to be identical for two individuals since it is constructed in the mind of the individual. In this respect von Glasersfeld maintains that he dissociates himself from Vygotsky's view of knowledge when he announces that:

> Vygotsky, living and writing in the climate of dialectical materialism, takes for granted that things are what they are and that 'in reality the child is guided by the concrete, visible likeness' to form associative complexes, or 'pseudo-concepts' which are then modified and tuned by 'verbal intercourse to the adult'. This last assertion is the only one I do not agree with. For Vygotsky, 'the same' (in this context) meant the real-world referents of the words. (von Glasersfeld, 1995, p. 142)

It is remarkable that it is just in this respect that von Glasersfeld, as the advocator of a radical constructivism declares a different opinion from Vygotsky who initiated another epistemological approach namely; the social constructivistic perspective on learning.

Vygotsky (1934/1986) emphasises the importance of social interaction and the dependence of language and thinking for our knowledge building. The relation between language and thinking Vygotsky described as a mutual developmental process even if they do not always run parallel. Linguistic thinking is perceived as a form of inner speech developed from the child's external speech. Vygotsky grounded this statement on Piaget's (1929/1975) analysis of the development of the child's thinking as dependent on that it masters the thinking's social tool, namely the language. Vygotsky contended that scientific concepts matured earlier than everyday language for school children. He attributed this early development of scientific concepts to the clarification of concepts made by teachers. Consequently, education of scientific concepts prepares the way for development of everyday concept (Vygotsky, 1934/1986).

While Piaget saw learning and psychological development as two independent processes, Vygotsky argued that conceptual development takes place in close connection with education and learning processes. Education therefore has to support functions that are maturing and not build on functions that have already matured. Learning builds on the foundation that the child learns by imitation, collaboration and adult guidance. When assessing the stage of development for a child one cannot just examine its present stage of development but you also have to consider functions that are developing. The educational system therefore has to support functions that are maturing, i.e., in the zone of proximal development (ZPD), defined as: "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1930/1978, p. 86). Vygotsky believed the role of education to be to provide children with experiences which are in their ZPD, thereby encouraging and advancing their learning. The connection and dependence between a child's linguistic development and thinking therefore becomes one of Vygotsky's most important pedagogical contributions.

In the constructivist conception of knowledge as individually and co-constructed and the view that knowledge cannot be transmitted "instruction should consist of experiences that facilitate knowledge construction" (Jonassen, 1999, p. 217). To support and engage learners in knowledge construction Jonassen suggests designing constructivist learning environments, (CLEs). Such CLEs should provide and encourage conversations about the problems the students are working on, and give access to shared knowledge building tools to help learners to collaboratively construct socially shared knowledge (ibid.). By creating such learning environments we engage students in "conceptual and strategic thinking, in contrast to reproductive learning" (ibid., p. 286). Technology should in a social constructivistic perspective be used to engage learners in "cooperative learning, where they collaborate with each other and socially negotiate the meanings they have constructed" (Jonassen, Kyle, & Brent, 1999, p. 218). In a reconstruction of constructivism into 'constructionism' Papert (1993) contends that this educational -ism "attaches special importance to the role of constructions in the world as a support for those in the head, thereby becoming less of a purely mentalist doctrine" (p. 143). After studies of students' work with computers

Papert emphasises that “computers would not simply improve school learning but support different ways of thinking and learning” (p. 178).

Epistemology informing the design

This thesis takes its epistemological starting point in a socio-cultural approach where knowledge building is seen as a situated and social process. The socio-cultural perspective implies studying and analysing activities of learning where people interact with each other and various physical tools. In line with the concept of mediation by technology in teaching and learning (Säljö, 1998; Wertsch, 1991; Vygotsky, 1930/1978) digital learning material is regarded as a tool for the students’ scientific reasoning about the subject.

The constructivistic principle that knowledge cannot be transferred from one person to another in a readymade package has profound implications for institutionalised education. One of these consequences is that students should be confronted with thought provoking problems in order to stimulate their construction of knowledge. Within this constructivistic view of learning, technology has been used as an important means of bringing in real world experiences into education:

> “The process of integrating constructivism into educational practice is clearly mirrored in the field of educational technology which, like education generally, draws on constructivist theories of learning to justify pedagogical innovations that encourage “everyday thinking” within “authentic” tasks in an attempt to situate learning.” (Petraglia, 1998, p. 5.)

In the broad sense of constructionism adopted by Petraglia an “encompassing notion of context” has to be acknowledged; “one in which everyday social, cultural, and material constraints cannot be discounted when studying learning or formulating pedagogical approaches” (Petraglia, 1998, p. 4). This notion of constructionism entails consequences for the design of technological learning material and how it is employed in education.

From the epistemological standpoint taken in my research, the digital material is seen as a tool, mediating certain scientific concepts. The analytical focus is, however, not the digital tool itself, but more how it is used and construed by the learners. According to the social constructivistic approach taken in this thesis, knowledge is built up by individuals from their mutual experiences and is modified in social interaction. To study the learners’ socially constructed meanings the exploration of the digital learning material was organised in such a way that they worked collaboratively in dyads or sometimes in triads with the task of describing what was happening in the animated events. The students’ interaction with the interface and with each other is assumed to constitute a base for their scientific reasoning about the described phenomena. This organisation, with the students working collaboratively, on the same task, faced with a computer screen also offers the possibility of making the interaction between the individuals, and between the students and the interface visible for analytical purposes. Acknowledging the socio-cultural view of human reasoning and learning as situated and contextually dependent the studies were conducted in natural educational settings where the digital learning material was integrated into the curriculum.

Research design

This chapter gives a background for the research organisation and an overview of how the studies were organised in order to obtain the empirical material. Studies of learning materials in science education have, so far, mainly concentrated on learning outcomes in quantitative terms. However, the change of epistemological focus from what might be taking place in 'the heads of' individual learners, prevailing in the 1970s and early 1980s, to what is taking place 'between and among' learners in their interaction (see chapter 3) calls for another set of empirical studies. This shift towards the group as the unit of analysis can be seen as an elaboration of the social theory of mind outlined by Vygotsky (1930/1978) and in line with the awareness of the community as the location of situated learning (Lave & Wenger, 1991). In a socio-cultural analysis the collaborating group has become the unit of analysis where participants in their interaction with each other and with cultural tools display understanding for each other.

For the purpose of the research project a digital learning material was created and studied *in situ* as an integral part of a lesson plan. An underlying knowledge interest is to identify pedagogical potentials as well as shortcomings of animations in science education. A general assumption among researchers in digital technology is that "probing into detail about learner behaviours/activities so as to be able to provide instructional designers and software producers with appropriate models of what learners do" would imply that "the tools could be more suited to learner preferences" (Säljö, 2004, p. 490). Hence, a rationale informing the study is the assumption that the better we understand students' collaborative reasoning on a given topic the better we can design special digital learning applications and learning environments in which this support is intended to serve. Evaluating new educational technologies also raises the problem of how such devices influence the students' emerging conceptualisation.

This thesis builds on two consecutive studies of students using the same digital material. In the first study the lesson and the students assignments were discussed and prepared together with the teachers involved. The lesson was documented in several ways: by video recordings of groups working with the animations, by the students' written accounts of their assignment and by interviews of the teachers. Results from the first study were analysed and discussed with the teachers involved. This dialogue together with the research results informed the design of the teaching sequence and the formulation of students' assignment in the second study. Thus, outcomes from the first study informed the second study regarding design of the teaching sequence, task formulation and enactment of the practices even though the same animated software was used.

Case studies in multimedia research

Meaning is not made of language exclusively and is always used as part of a complex cultural activity, accompanied by gestural, postural, proxemic,[18] situational and paralinguistic information (Lemke, 1998). When the analysts have access to these gestural and pointing movements the indexical[19] referring in spoken language can be discerned. Lemke (2004) also points out that in a socio-cultural discourse analysis the concern is for the language content, function and the ways shared understanding is developed in social context. Here the meaning of any discourse always depends on how it can be connected to some events, for example, what students say in a particular situation may make meaning in relation to the history of his/her experiences. This dependence of the context for interpretation of an ongoing activity makes it necessary for the educational researcher to get as much data as possible regarding former teaching activities, group dynamics of the class and the subjects' interest for the topic, cultural background and so forth (ibid.). Lemke (2004) furthermore underlines that the context-sensitivity of any meaning making activity in education strongly suggests that the learning process has to be studied *in situ.*

A fundamental question is then how to accomplish research on multimedia use in which different people make diverse meanings with complex media artefacts and what should we be seeking to learn in those activities. From a socio-cultural perspective of learning (Crook, 1994) argues that:

> If we do wish to conduct evaluations of what is learned in computer-based contexts, we must go beyond the input-output designs that characterise much research in the area. It may not be enough only to expose a pupil to

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

[19] Indexicals are linguistic expressions whose reference shifts from context to context, some examples are 'I', 'here', 'now', 'today', 'he', 'she', and 'that'.

> some software and, some tine later, do an outcome test of understanding. The reason this is inadequate is because any such computer experience is more or less situated in some broader framework of teaching activity. In short there is a risk of casting this educational technology in terms that suggest a medical model of how it works. (p. 9)

Still several years later, Lemke (2006) proposes that we should leave the prevalent approach in educational research that takes its point of departure from an implicit input-output model where the direct relations of cause and effect should allow us to determine what causes what. Even in the ISTE report it is suggested that "other research designs are needed to establish causality" and that such large-scale studies could be complemented by "more extensive qualitative classroom studies that examine these relationships in a more fine-grained way so as to establish casual mechanisms" (Kozma, 2003, p. 237).

Comparative studies in education have been unable to confirm any general measurable learning benefit attributable to technology (Russell, 1999). This may be due to the fact that "most treatment variables in educational studies are found to make little or no difference, whereas individual difference variables account for a large part of the variance in outcomes" (Bereiter, 2002, p. 326). Suppose, for example, that one educational technology may be better for high-achieving students and another teaching aid would be better for low achieving ones, with the result that, averaged out over all students, there will be no discernable difference in effect (ibid.). Schnotz and Rasch (2005) found, for instance, that manipulable pictures had an enabling learning function for students with high learning prerequisites whereas animations had a facilitating function for individuals with low learning prerequisites.

Social systems seem to have such complex interdependencies that no single input reliably governs any particular output and every effort to control some outcome runs the risk of producing unanticipated and often uncontrollable side effects (Lemke, 2006). Instead of the input-output model Lemke suggests a "tracer" model where we follow in detail the actual processes by which outcomes are achieved. We should thus aim for an understanding of how any particular social system mediates chains of cause and effect that runs through them. Having done this for many different systems we will learn to be sensitive to the kinds of mediations, interactions and differences that are most likely to matter to our interests (ibid.). More in-depth studies of students activities is also advocated by Goldman, Pea, Barron, and Derry (2007) who argue that quantitative studies do not explain "the meaning that people ascribe to the events they experience in learning environments" but that "ethnographic accounts tell rich stories that help us to understand the meaning of events"[20] (p. 25).

There can, however, be objections made that studies based on qualitative data do not generate generalisable results. Regarding the generalisability of such case studies, Stahl et al. (2006) contend that:

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

I am convinced that such case studies together with Lemke's recommendation of conducting such studies for many different systems will produce general insights in how multimedia is used and construed in school settings and about how to design learning activities involving educational learning material.

Group work

Taking its starting point in a constructivistic perspective, the orientation of the research concerning computers and learning has initially been towards the relationship between the representational technology and the individual learner. From a socio-cultural perspective, it was stressed by (Crook, 1994) that the "meaningful relationship" afforded by the technology might be "what is held in common with others and creative collaborations may be especially enhanced by this possibility" (p. 228). Since then, learning in small groups, in computer mediated environments has received a growing interest from educational researchers (e.g., Klein & Doran, 1999; Mulder & Swaak, 2002; Springer, Stanne, & Donovan, 1999).

In the emerging theory of computer supported collaborative learning (CSCL), interaction analyses of knowledge building in small groups is an important methodology. Stahl (2006) argues that group learning or 'group cognition' has an advantage over individual learning because the meaning making process builds on the participants' different interpretations and the interlocutors accomplishment of an evolving meaning. Computer supported collaborative learning does not just take the form of online communication which imply that CSCL likewise is concerned with face to face (F2F) col-

[20] Ethnographic research aims to discover the cultural knowledge that people hold in their minds, how it is employed in social interaction, and the consequences of this employment (Spindler & Spindler, 1992)

laboration (Stahl, et al., 2006). "In this case, the collaboration focuses on the construction and exploration of the simulation or representation" (ibid., p. 410). To capture the shared knowledge building which is going on during collaborative interaction, meaning making can be analysed as taking place across sequences of utterances from the participants (ibid.).

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

> The students are, hence, familiar with the fact that school tasks are usually developed in certain ways. When they do not come to agreement about how to understand the task, the strategy of looking at the task from the non-present designers' perspective becomes an important resource for them in their continuing understanding of what the task entails, for their continuing problem solving and, thus, for their development of knowledge. (p. 101)

Thus, the formulation of tasks and instructions is of great importance for how the learning material is understood and what kind of knowledge the students will acquire in their joint activity of fulfilling their assignment (Bergqvist, 1990; Greiffenhagen & Watson, 2007; Lantz-Andersson, 2009; Lund & Rasmussen, 2008; Nishizaka, 2000).

Arranging the setting

For the purpose of studying students' interaction in connection with the use of digital learning material the learners have to collaborate on a given task on the same computer during a video-filmed session. The question then arises about the appropriate number of students working together in the activity. When working collaboratively in front of a computer screen the physical arrangement of the interlocutors and monitor make limitations to the students' access to the interface at the same time as they participate in discussing the observed phenomenon. Gestures and gazes constitute a central role for communicating in connection with representations, as they are important to identify deictic referents to the representation media (e.g., Goodwin, 2000; Lemke, 2006; Mondada 2006). Roth (2001) contends that, although a group size exceeding two individuals does not exclude participation in the conversation it curtails their mutual orientation and their active engagement in the interaction by preventing them from gesturing (p. 45). The arrangement of two students working in front of a computer screen seems to be ideal as it helps a speaker to make salient those aspects relevant to his or her explanation but if the physical arrangements allow, three or even more learners can be working together (ibid.).Hence, in order not to impede any participant's opportunity to partake in the communication, the preferred group size in the two studies, presented in this thesis, was limited to two students, although, in a few cases there were three students in a group, due to practical circumstances.

The arranging of an educational setup for research purposes evidently challenges my initial claim of conducting research in a natural school setting. One can of course call into question what constitutes a natural/authentic school setting. Simply the circumstance of having research conducted in a classroom is not what would be termed as a natural school situation. Furthermore, the video filmed groups presenting the cases in the two studies were separated from the other groups during their work with the digital material; however, all students in the classes were exploiting the material simultaneously. The separation of the filmed groups was made in order to allow the video recordings to be analysed without disturbing noise from surrounding groups. In spite of these somewhat exceptional situations, I have chosen to regard the two studies to be the same as in a natural school setting. There are mainly two reasons for this decision. First, if a research situation, per se, would exclude a study from being described as occurring in a natural school setting it would exclude any studies in classrooms to make the claim of being conducted in a natural setting. Second, even though the video filmed groups were placed in separate rooms during their work in front of the computers they were part of the whole educational setup. Besides, it is not an unusual situation for groups being separated during computer work due to the fact that computers are unevenly allocated in schools.

Video recording as an analytical tool

Linguistic semiotics in the form of spoken language or text can be made visible retrospectively to the researcher through tape recordings and written documents respectively. For other communicative resources in naturally occurring interactions video is unique in its ability to make available in retrospect what is happening in an interaction. Video recording bears with it the possibility of exposing different kinds of communicating resources and to "examine past activities not as *past* but rather as 'formerly present" (Laurier & Philo, 2006, p. 188). In a study of two such completely dissimilar activities such as girls playing hopscotch and archaeologist at work Goodwin (2000) demonstrated from videotaped materials how construction and interpretation of human actions are accomplished through talk, body displays and material structures within a situated interaction. Material structures in the surround "can provide semiotic structure without which the constitution of particular kinds of action being invoked through talk, would be impossible" (ibid., p. 1489). Different kinds of semiotic resources are made publicly visible through the human body as a site for a range of structurally different kinds of displays.

The increased use of video also coincides with an epistemological growing interest in the role of tools and artefacts in a social constructivist perspective of learning (e.g., Säljö, 1998) and a more praxeological perspective[21] in educational research (e.g., Mondada 2006). These perspectives motivate an in-depth study of how learning is interactively accomplished in an ongoing activity. In their seminal work on video technology and interaction analysis Jordan and Henderson's (1995) state that:

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

Video recordings afford an opportunity for the researcher to become aware of multimodal means for human communication. Lemke (2006) emphasises that all human semiotic resources such as speech, various body-gestures form an integrated system of communication for meaning making and hence, all communication is multimodal and has to be studied as such. To understand multimedia, we need research on how people use this kind of media in various ways because readers differ in how to interpret semiotic signs (ibid.). Thus, an apparent advantage with adopting video in research on learning is the opportunity to reveal the multimodal resources humans use in interaction such as linguistic features, gestures, gazes, body movements and object manipulations.

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

For the purpose of educational research, video analysis has proven to be a useful tool. So, for example, did Roth (2001) identify patterns that simultaneously occurred at multiple levels by analysing video data from a physics classroom where students learned to explain computer-animated micro worlds. Video analyses of learning activities have brought into focus representational artefacts, social configurations, physical arrangements and students' interaction. As pointed out by Goldman, et al. (2007):

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

Video recording thus, constitutes a powerful tool for generating data for analyses of students' understanding of an educational intervention and provide means of unravelling what is going on in an educational activity. By video analysis it should be possible to find out how students perceive various aspects when interfering with a represented phenomenon and to bring into focus students' description of an event.

Video analytical methods are also called for as a consequence of an emergent interest in design based experiments that can be of direct use for educational practice (see Introduction p. 5). Analysing learning and interaction in retrospect offers educational research a unique opportunity to provide answers not only about what works and what does not work but also about how it works and why it works in a certain way. Analysis of video recordings where students are interacting with each other and the interface affords valuable information about how such educational software is used and construed. This quality of video research is an important aspect when the research is concerned with design and development of educational aids. As remarked by Bereiter (2002): "When the observer is interested in design, much can be learned about how to improve a design by observing it in operation" (p. 324). This is particularly true in design based research where it is important to get detailed information about how and why an educational intervention works (Koschmann, Stahl, & Zemel, 2007). However, the task of design and analysis must be treated as distinct activities, which does not mean that design and analysis is independent, instead design must be informed by analysis but analysis also depends on design in its orientation to the analytic object (ibid.).

Analytical approach

When left with a large set of qualitative data—in the two studies reported in this thesis, mainly consisting of video recordings—one are confronted with the question of how to analyse it. One way of performing the analysis is to quantify the empirical material by making up categories in order to classify the observations for frequency distributions (e.g., Hakkarainen, 2003; Kumpulainen & Mutanen, 1999). As to the advantage of a categorising method of interactional data Stahl (2002) points out that,

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

Inevitably, however, the coding of statements results in a reduction of rich interactional material. Stahl (2006) states that "the reduction of a rich discussion in a database of students notes into counts of how many note fragments ("ideas") fall into each of several categories represents a loss of much information" (p. 219). Stahl also points out that: "Collaborative knowledge building is a complex and subtle process that cannot adequately be reduced to a simple graph or coding scheme, however much those tools may help to paint specific parts of the picture" (p. 221). Since the students' meaning making process by the coding becomes frozen and dissected "the coding procedures place severe restrictions on the attempts to capture the situated dynamics of peer group interaction" (Lindwall, 2008, p. 40). Thus, dividing the material into preconceived categories inexorably results in that the real nature of students' meaning making process risks being obfuscated.

For the purpose of capturing the details of the students' interaction with each other and the interface an analytic approach that draws on a tradition which Jordan and Henderson (1995) summarise under the label 'interaction analysis' has been employed in the studies reported in this thesis. Through detailed analysis of videotaped material, this analytical framework tries to describe the ways participants coordinate both communicative and material resources when performing a given task (Ivarsson, 2004). I find this interdisciplinary method particularly helpful for empirical investigation of technology-mediated learning environments.

Interaction analysis of video recordings

In accordance with Jordan and Henderson (1995) instructions, I as the researcher, have attempted to the largest extent possible, to keep "free from predetermined analytic categories" (p 43). Such categories are instead expected to emerge from the "deepening understanding of the orderliness of the interaction as participants on the tape make this orderliness visible to each other" (ibid., p 43). As prescribed by Jordan and Henderson, the analysis started with viewing the video recordings and making a content log for an overview of the data corpus for locating particular sequences of interest. Jordan and Henderson (1995) declare that naturally this will mean that the researcher's preconceptions will be imposed on the analysis. One way to redeem this bias of the researchers own view is to show the selected segments in an interdisciplinary work group of researchers: "Collaborative viewing is particularly powerful to neutralize preconceived notions on the part of researchers and discourages the tendency to see in the interaction what one is conditioned to see or even wants to see" (ibid., p. 44). Hence, the selected segments were demonstrated and commented on in a group of researchers concerned with interactive learning. After these sessions, segments representing the analytical thinking of the group remained. Jordan and Henderson declare that "it is incumbent on the researcher to assess which observations are of general patterns" and that "this is done by finding other instances of the event in question in the data corpus and checking whether the proposed generalization holds" (p. 46). In line with abovementioned directions representative episodes were chosen for detailed analysis and presented in the articles included in this thesis.

Video analysis makes use of various analytical methods. The studies presented in this thesis draws on methodologies such as conversation analysis (CA)[22] and ethnomethodology (EM)[23]. For studying students' interaction with each other and the interface, I consider both of these analytical approaches to produce detailed case studies. While not directly aimed at video recorded material obtained in a technology mediated setting there are, however, considerations to be made when applying these methods on such data.

In an attempt to extend conversation analysis (CA) to cases of face to face collaborative work in front of a computer screen, Greiffenhagen and Watson (2007) raise questions of how to study instances of visual communication. For analysing video recordings of human computer interaction they studied

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[22] Conversation analysis (CA) is an analytic approach to study verbal conversation. Through the repeated analysis of small fragments of talk, CA aims to recover methodical practices such as 'taking turns', 'repair and correction' and 'preference organization' (e.g., Sacks, Schegloff, & Jefferson, 1974).
[23] Ethnomethodology (EM) is centrally concerned with practical reasoning and the procedures participants use in making sense of their own actions and the actions of others(Garfinkel, 1967, 1988).

how the interlocutors applied the phenomenon of 'self-correction' and 'repair'[24]. The authors argue that despite the occasional usefulness of CA as a fruitful heuristic device to highlight aspects of interaction they could see problems of applying CA directly to instances of visual conduct. So, for example, is 'repair' in ordinary conversation tied to the achievement of shared understanding since one co-participant has to gain understanding of the other. On the other hand, in instances of teamwork in human-computer interaction it is not so much that the students have problems of understanding each other but more about what they interactively are trying to achieve. Considering the question of applying a model of CA to the analysis of human computer interaction, Greiffenhagen and Watson argue that their work "suggest that rather the wholesale transposition of a model of conversation, we should be thinking instead of bringing to bear the 'analytic mentality' of this approach" (p. 29). The authors furthermore argue that two elements from CA could prove especially helpful in analysing human computer interaction; first an emphasis on participants as analysts where the features of collaborative work at the computer are oriented to by the participants and second by emphasizing students' culturally based sense-making practices not as an individual phenomenon but as a socially organised one.

For doing video analytic work in support of design based research Koschmann, Stahl and Zemel (2007) propose the method of applied ethnomethodology (EM). The authors argue that because of EM's central concern with practical reasoning and meaning making practice, it would present a useful foundation for video analytic research. In the article Koschmann, et al. analyse Garfinkel's (1967) five policy statements for ethnomethodological research and its implications for video analytical work. Their proposition can be summarised as[25]:

- Any instance (i.e. a single case) will do for the purpose of demonstrating some phenomenon of interest.
- Video technology is a valuable tool for performing a sequential analysis of a contingently achieved accomplishment since it enables analysis on a detailed level and provides for repeated inspectability of the recorded materials.

[24] The concepts of 'self-correction' and 'repair' in conversation are described by Schegloff, Jefferson, and Sacks (1977).
[25] The summary is made freely by the author from the article Koschmann et al. (2007).

– It is the task of the video analyst to demonstrate in their empirical material what the participants count as relevant and what sense making is produced in situ.

– The analyst's job is also to document what the participants are doing, rather than what they should be doing based on prior expectations.

– The context dependent and context shaping character of participants' talk and action poses the task for the video analyst of rendering an account of how members go about constructing context though their indexical actions.

Their conclusion is that EM, as a discipline, focusing on members' methods for practical reasoning, provides a useful foundation for research into the practices of learning.

Re-presenting video material

The undertaking of 're-presenting' video data for an audience in printed form involves significant problems. Since audiovisual material often presents a variety of conducts and incidents displayed by the participants it renders the analyst with the problem of transcribing the multimodal actions to be reconstructed by the reader as they appeared in the first place. As expressed by Goodwin (2001) "When it comes to the transcription of visual phenomena we are at the very beginning of such a process" (p. 160). For the purpose of capturing the chronological characteristics in conversation G. Jefferson[26] developed a transcript system, furnished with notations, that enables the reader to follow and inspect the analyst fragments. Traditionally this transcript convention, adopted from a CA tradition, has been used for demonstrating analysed video sequences for the reader. However, the problem with this type of transcript is that it only captures selected aspects of the interaction and does not allow for displaying visual conducts for example, gestures or manipulation of devices.

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

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[26] The Jeffersonian transcription conventions are outlined in Atkinson and Heritage (1984).

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

This lack of a convention for re-presenting video materials in printed form still remains. As predicted by Jordan and Henderson a variety of modes have emerged to extend transcripts to systems for demonstrating visual conducts. Some examples of alternative moods for presenting video material in papers are:

- combinations of written transcripts with arrows directed at sketches of, for example, a gesturing or pointing hand (e.g., Goodwin, 2000)
- transcripts accompanied by matching screen shots (e.g., Nishizaka 2000; Mondada 2003)
- transcribed data fragments, presented on time lines illustrating the order and extension of events combined with screen shoots (e.g., Greiffenhagen & Watson, 2007; Mondada 2006).

These examples of different modes of 're-presenting' analytically important episodes demonstrate on the one hand the authors' efforts and dedication to exhibit detailed visual aspects of their empirical material and on the other hand the difficulties of conveying multimodal actions to an audience in printed form. The driving force behind the inventions of new modes for re-presenting video materials is primarily to provide the reader with the possibility to re-construct the depicted events as they appeared on the video sequence. Different analytically viewpoints require diverse types of representations and the researcher always has to choose the representational form that she/he thinks best characterises the analysed material.

A mode, in the making, of demonstrating visually complex events in a video sequence of interest is 'comic strips' also referred to as 'sequential art' (e.g., McCloud, 1994). In this form of representation it is the possibility of illustrating the sequentiality in what the participants do and say, often simultaneously in an act which makes sequential art an interesting style. This mode of representation affords for the analyst to present actions in a comprehensible form to the reader. I believe sequential art to be a promising candidate for complementing the variety of already existing representational styles for video material, mainly for two reasons. Firstly, it is conventional and thus, easily accessed, especially for readers not familiar with CA conventions. Secondly, with screen shots from the analysed video fragments one are able to exhibit visual conducts, not so easily conveyed in written form.

For representing the analysed video excerpts in the studies reported in this thesis; the first article makes use of a traditional form of Jeffersonian transcript while in the second article analysed fragments are represented in the form of sequential art. All modes for *re-presenting* audio-visual material in printed form inevitably lack some of the information from the original videotape. When presenting the excerpts in frames with speech bubbles as in sequential arts, there is a loss of some of the information available in a CA transcript such as intonation, pausing, overlapping speech, et cetera. In Study II where the transcripts are presented in strips a conventional transcript is therefore appended in order to complement with this information for the ardent reader.

Summary of studies

Animations in science education

In this first study, the theme is to explore pedagogical consequences of the animated application displaying gas exchange in the carbon cycle. The specific field of investigation concerns science education where students' reasoning and interaction when working with the animated sequences is examined. From a total of 40 students attending a science course in a Swedish secondary school, three groups were randomly selected and videotaped during their work with the learning material. There was no tutorial introduction of the topic before the students started exploring the learning application but a short instruction was given about how to navigate on the web-site. The students were given the assignment of writing down what they saw happening in the different sequences when they had worked with the animations for 20 minutes. During this time, while having access to the learning application and the possibility to consult their teacher, the groups were supposed to discuss and jointly give written accounts about what was happening in the animated processes. Through detailed interaction analysis of the videotaped material it is examined how the students in the three video recorded groups understood their task and reasoned about the animated events.

The analytical result of the video material presented three problematic outcomes of the students' task of describing the events displaying the gas exchange. The first two of these is related to the features of the technology and can be characterised as *misguided attention* and *isolated reasoning* respectively.

Misguided attention was manifested in the students focusing on misleading aspects of the animation. Examples of such misleading features of the animation are observable in some of the students' everyday expressions like, “molecules get stuck” and “blow away”. These specific wordings are subsequently adopted by other members of the group and even taken up by their teacher. The students’ tendency to focus on prominent features of the animation, to incorporate everyday language in their description and to impose simple everyday cause-effect relations on the depicted processes is also described by Lowe (1999; 2003). The findings furthermore demonstrate how easily such inferred notions are accepted and taken up by other students and even by the teacher.

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

Conflicting perspectives represent the third observed unintended consequence and has to do with the students’ varying ideas of what resources they are expected to make use of when performing the given task. These *conflicting perspectives* resulted apparently from the formulation of the students’ assignment, which was expressed as: “explain in your own words what you can see happening in the different animations”. When analysing the students’ understanding of this seemingly straightforward instruction it was shown that it caused conflicting discussions in two of the three groups. The conflicts among the participants were about how to accomplish their assignment. Their quandary concerned whether or not they just had to explain what they could ‘see happening’ in the animation, as is explicitly expressed in the instruction and thereby disregard what is said in the explanatory text and what they already know about the processes; or should they use all available resources to explain what was happening in the animated sequences. Even though the intention with the assignment was to make the students draw their own conclusions from the animated sequences, the formulation of their task in fact created an increased uncertainty of how to proceed. Considering these outcomes, it seems important to pay careful attention to the formulation of the task that students are going to perform in their work with learning material.

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

Animation and grammar in science education

Learners' construal of animated educational software

This second article reports an expansion of the first study where instructions and assignments were used together with the same learning material as in the first study. The analytical point of departure was the meaning making processes taking place when students collaborate on construing the animated processes of the carbon cycle. In the article it is elucidated how students endeavour to make a joint description of what they can observe in the animated sequences and learn from the accompanying educational texts. The analysis specifically inspects how learners make use of available semiotic resources in their effort to construct a written account of what is happening in the animated processes. When describing linguistically an event, learners face the problem of grammatically constructing sentences of what is happening. “The sentence in its basic structure consists of a verb and one or more noun phrases.” (Fillmore, 1968, p. 21) The problem of lexical selection of verbs and nouns for insertion in a sentence depends grammatically on so-called ‘frame features’ into which a given verb may be inserted (ibid.). When studying how conceptual representations of visual events are mapped into language we should start by looking at the ‘attentional focus’, “size and animacy (or at least motion) represent—completely independent of language—characteristics of objects which attract attention” (Tomlin, 1997, p. 182).

Results from the initial study revealed some problematic outcomes of the students’ interpretation of the animated processes. In an effort to alleviate some of these problems the students in this subsequent study were given a lesson introducing the subject to provide them with more profound background knowledge of the field. To avoid the conflicting perspectives among the students—observed in the first study—of what resources they were expected to use, the assignment was reformulated in a more direct way. Students, aged 16-18 years in four classes, totalling 65 individuals, worked in dyads or triads with the task of describing what was happening in the animated processes. Seven of the groups were randomly selected to be video recorded during the entire session when performing their work with the animated software. By means of interaction analysis the video recorded material was examined to gain understanding of how the students made use of the computer application for their construction of their jointly written report.

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

The analysis demonstrates how the students struggle to find out logic in the mouldering process, matching it with the educational text and creating their own written description. They first comment on the oxygen molecules which they can see moving towards the decaying log. The oxygen molecules, from then on constitute the active subject in the students narration of what is happening in the mouldering process. The motion of the animated oxygen molecules makes them perceptually salient and by this, attracts the students' attention. Hence, the information the students draw from the animation is driven by this dynamic effect. In the students' construal of the animation they turn to the educational text in an attempt to get an explanation of what is happening. Although it was not mentioned in their assignment to use their own words in the description of what is happening in the events, they strive to find expressions that are more in accordance with their own way of articulating, than the vocabulary used in the educational text. The students' construal of the events is taking place in their interactional effort to grammatically construct a story from two different semiotic resources i.e., animations and written language. In the students' description of the mouldering process the oxygen molecules take the role of agents instead of the micro organisms as described in the educational text. This shift of agency and subject role can be attributed both to grammatical rules that allow inanimate objects to be given an agentive status and to the character of the animation that makes the oxygen molecules 'attentionally detected' (Tomlin, 1997). When framing their sentences, the students derive noun phrases from attentionally detected objects and from the educational text. In the students' effort to express themselves in their own words they use verbs that differ from the educational text. Grammatical rules allow the verb to be changed within the sentence frame (Fillmore, 1968). However, in the process of changing the verb the students also alter the agency of the subject. These courses of action together, contribute to give the students' report on what happens in the mouldering process a non-scientific explanation. Thus, the students construct a grammatically correct but not scientifically acceptable description of the event. Lacking definite access to the relevant subject matter knowledge they consequently cannot judge whether they have given an approvable account or not. The students' only way of assessing their written report is to check if it is grammatically correct, which they do by perusing the text. When they find that it 'sounds good' it makes them satisfied with their account.

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

Discussion

The analyses in the studies presented above are made on video recordings of students collaborating on assignments connected to an educational application illustrating the carbon cycle in animated sequences. Both studies present examples of identified interesting phenomena that could be generalised from more extensive empirical materials. The interventions have been made in a school context with the ambition to study outcomes of the use of digital learning material in a natural school setting. By means of detailed interaction analysis it has been possible to get an insight into learners' construal of the digital learning material and what consequences that entails for their potential understanding of the described phenomena. Hence, the presented analysis exemplifies how students in a school context understand a digital learning material which provides semiotic resources in the form of animations and educational text.

By this close inspection of students' understanding of the learning material it has been possible to answer the research questions initiating the studies. To summarise the following issues were initially raised about the digital learning material: how the students use and construe it, students' reasoning about the illustrated phenomena, how they frame their task of linguistically construct an account for what is happening and how the formulation of the task affects their understanding of how to accomplish the assignment. In this section I will discuss my results concerning these issues in relation to educational and design consequences.

Interpreting animation

Results from the studies reveal students' propensity for concentrating their attention to prominent characteristics of the animated display. This problem of students' detection of salient features in favour of more thematically relevant structures in animated learning material is also described by Lowe (2003, 2004). Furthermore, it was observed how students' and sometimes even teachers' described the animated molecular models in correspondence to their resemblance of objects and occurrences in every-day life. Molecules were, for instance, endowed with characteristics to "blow away" and "get stuck" as demonstrated in Study I. This mixing of scientific concepts with more colloquial language observed in dynamic representations may as well be attributed to static pictures (Han & Roth, 2006). It can, however, be argued that the dynamics in animation makes the model characteristics more pronounced than in a static representation and hence, even more accentuate learners' tendency to characterise the represented scientific concepts as recognised everyday features. Consequently, the special characteristics of the animation have an obvious significance for a learners' way of describing what is happening in an animated sequence.

Educational perspectives

In school settings the students are most often supposed to give a written account of their understanding of the studied subject. This was also the case in the two studied interventions where the students' were assigned to produce a written report of what was happening, in the animated processes. The students' assignment of writing a description of the events described in the learning material showed not to be such a straightforward task as one could anticipate. Study I elucidated the students' predicament over what resources they were supposed to make use of when describing what was happening in the animated events. It was shown that the animations' superficial representation of events did not always correspond with the students' pre-knowledge or what was expressed in their text books about what was actually happening in the processes. To some extent, this problem could stem from the formulation of the student assignment which was worded as: "Explain in your own words what you can see happening in the different animations". The observed different standpoints among group members were based on the belief, maintained by some students, that solving the task according to its literal formulation had precedence over a wider understanding of the subject. Students were also anxious not to re-use expressions from the educational text or textbooks in their own descriptions of the animated events in this first study. Consequently, the assignment was re-worded in a more unambiguous way in the second study as: "Describe what is happening in the processes". The problem of conflicting perspectives among students, over alterative resources to draw on, was not detected in Study II which points to the delicate problem of task formulation. However, even if it was not expressed in the students' task in Study II that the reports should be written in their "own words" it functioned as an underlying norm among the students when constructing their account. These observations emphasise the "need to further theorise the task-tool relationship in activities involving collective knowledge production and that we need to align pedagogical as well as technological designs in order to give support for such efforts" (Lund & Rasmussen, 2008, p. 387). It also points to the fact that when constructing and evaluating students' assignments in education one have to consider that "tasks are cultural and social constructions and there are certain cultural conventions of approaching and solving tasks" (ibid., p. 409). Hence, the findings from the studies show that the school context with its explicit stipulations of assignments and implicit request for expressing oneself in one's own words frames the learning and creates conditions for how the technology is used and understood.

The two successive studies were connected in a way that outcomes from the first study informed the educational framing in the subsequent study. This resulted in that the students' exploration of learning material was more integrated in the curriculum in study II where a lesson, explaining the carbon cycle, preceded their work. The students' assignment was also reformulated in order not to cause conflicts over what resources the students were supposed to utilise. Results from the analysis of the second study showed no direct influence from the preceding lesson. In just one instance it was observed that a reference was made to the previous lesson, with one of the students mentioning the photosynthesis, however, not in accordance with what had been conveyed by their teacher during the lesson. Overall, the students reasoning about what was happening in the mouldering process was restricted within the boundaries of information available in the educational software, namely, the animation and the educational text. Clearly, the results emphasise the importance of a guided and/or tutor-led debriefing following the students' exploration of the educational software. Here, the teacher has to build on what has been observed in the animations and exploit the students' observations and questions raised during their observations in the animations.

Researching animated learning material

The possibilities to demonstrate courses of events, provided by static representations are limited to directional devices as, for example, arrows. An animated representation provides the additional opportunities to endow objects with locomotive power, changing its shape, colour etc. These features of an animated display proffer new prospects for illustrating scientific phenomena for the purpose of science education. However, as the two studies have exemplified, new modes of representation also entail didactical complications in the learners' way of interpreting what is happening in the events. This poses a challenge for educational researchers to really go thoroughly into students' interpretations of the representation and to try to understand how this is accomplished. To simply label the students explanation as "wrong" instead of capitalising on the students effort to describe what they have observed, risks to result in on the one hand, the students feeling ridiculed and refrain from generating interpretations of the depicted phenomenon and on the other hand, a missed opportunity to build on the students idea to create more canonical conceptions (Roth, et al., 1997).

Normally a teacher or someone else evaluating the outcome of a learning intervention simply has access to the end result of students' efforts to understand and make an account of the to-be-learnt matter. With the use of interaction analysis performed in the studies which this thesis builds on, it has been possible to acquire an insight in how learners reason about and understand the topic described in a digital learning material. This analytical approach also gave access to students' methods of interactionally accomplishing a linguistic explanation of the events.

Prospects for animated learning material

Despite the problems of students' interpretations of the animated phenomena, the results on two points indicate that computer animated learning software can proffer an exploitable resource in science education. One of these prospects for animation in science education is its ability to engage students in discussions over a subject. A general observation of all the 105 students participating in the study was that they enthusiastically engaged in group discussions over the content in the digital learning material. According to their teachers, this was not what could have been expected if they had been requested to perform the same kind of work, not having access to the software. In a similar vein, when studying two boys working with graphical simulation of the concepts of velocity and acceleration, Teasley and Roschelle (1998) remark that, "in ordinary circumstances, one cannot imagine two 15 year olds sitting down for 45 minutes to construct a rich shared understanding of velocity and acceleration" and "we see the "computer-supported" contribution to collaborative learning as contributing a resource that mediates collaboration (p. 26). Hence, I consider digital learning materials capacity to encourage discussions about a scientific phenomenon to be one of the most promising prospects for computer animated material as an educational tool. A caveat should, however, be made about the engaging capacity of computer animations for students collaborative learning. Digital learning materials are not in regular use in schools in general and were extraordinary at the school where the reported studies were conducted. Consequently, animated learning material is probably a new experience for most of the students and therefore engagement in the activity may have had the charm of novelty. In order to make a more grounded statement about animated learning materials potential of engaging students in shared understanding of the simulated subject these kinds of novel learning devices have to be in regular use in school practice where research is conducted.

As already mentioned, students' general understanding of air as containing matter in form of gas molecules is very low and educational efforts to augment learners' realisation of this fact have not resulted in any marked effect. In view of these low learning results one cannot expect that a single animated learning material by itself should produce revolutionary effect on the students' understandings of the gas exchange in the carbon cycle. However another observation from the study, indicating animations potential as a teaching aid, is that the students recognised and talked about the molecules as an existing entity in the air, however, not in a sense that could be considered to be fully scientific. This realisation of air as containing matter in the form of molecules provides a foundation for an understanding of processes in the carbon cycle and can be seen as a promising aspect of the learning material.

Design consequences

The already described problems of outstanding features taking precedence over other less conspicuous but thematically relevant features and isolated reasoning about complex processes, poses a special problem for animation as teaching aids. We have seen molecules being described with similar characteristics as everyday objects. Another example is the isolated reasoning observed in study I, where students' description of a complex biochemical process became limited to just a part of the process. Such unintended interpretations made by the students of the animated learning material can be attributed to the simplified character of the animation. The design of the animated sequences may to some degree be modified to rectify such undesired interpretations, although we have to take into consideration the limited capacity of the media to convey complex natural phenomena. Animation like any model of a scientific concept brings with it simplifications and exaggerations of certain characters (Han & Roth, 2006). Hence, complex molecular processes occurring at different levels simultaneously cannot be realistically portrayed in an animated display. A biochemical process, as the word "process" signifies, involves some kind of activity. This process is often intracellular and taking place at several levels simultaneously and thus, virtually impossible to visualise as it occurs in nature. In an animated display one also have to show biochemical reactions that are taking place over a substantial length of time, days, weeks or even years in just a few seconds, as in the case of the mouldering process discussed by the students in Study II. To illustrate an ongoing activity in such a process the designer, inevitably, have to bestow some of the objects in the display with locomotive power. This risks giving these objects an agency and activity (Tomlin, 1997), and as a consequence runs the risk of leading the observer to an unscientific construal of the event. Suggested means to cope with such problems, originating from simulated displays have been through increased interactivity (Tversky, et al., 2002), activities that generate explanations or to answering questions during learning (Mayer, et al., 2005). When considering re-designing computerised 3 D molecular models to overcome problems with students' undesired interpretation Krange and Ludvigsen (2008) remark that:

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

Consequently, regardless of how sophisticated animated learning material becomes, there will always be grounds for misinterpretations, risking fostering unintended interpretations. Also, there seems to be no uncomplicated and immediate way of designing an animated display to overcome such drawbacks.

A possible way of advancing the animated sequences of processes in the carbon cycle might be to illustrate what is happening inside organisms by viewing enlarged parts of an organism to show, for example, micro organisms inside a mouldering plant or body cells in the human tissue. Such an expansion of the animation with additional details risks, however, making the representation more complex and hence, more demanding for the learners to understand (Mayer, 2001; Mayer & Moreno, 2002). Another way of designing the animated learning material to facilitate students' understanding of the depicted phenomena could be to elaborate on the explaining text to make it more informative. It is, however, questionable if a more extensive text will result in better understanding of the phenomenon but might instead lead to students refraining from reading the whole text.

Within a multimedia presentation one also have the possibility to employ additional modalities for example, a voice explaining the events occurring in the animation. Mayer and Moreno (2002) contend that, "students learn more deeply from animation and narration than from animation and on-screen text" (p. 96). The application was, however, not furnished with a voice, due to equipment and communication restrictions. Yet, in a further developed version of the educational material it might be a learning advantage to replace the educational text with a spoken narrative.

Conclusions

The studies have revealed several complications with students' understanding of the animated learning material and from the results one cannot claim digitalised learning materials supremacy over previous learning aids for teaching scientific concepts. Neither have other studies of animation in education found consistent proof of animations primacy over traditional learning devices (Tversky, et al., 2002). One may then argue that animated learning material does not enhance learning of scientific concepts and should be abstained from as a teaching device. Taking such an argument as a motive for refraining from further research on educational use of animated learning material would be to 'throw out the baby with the bathwater'. There is, and probably never will be, any learning device affording a panacea for learning abstract natural phenomena. Scientific achievements that have taken centuries of research and intellectual efforts to accomplish will not easily be conceptualised by means of a single educational intervention or a learning device. Digital learning material has to be developed and refined by 'sustained innovation' to be capable of proffering an alternative to well-trained learning aids (Bereiter, 2002). As shown by the results from the studies presented in this thesis, there are factors that can speak in favour of educational animated learning material and there are developmental possibilities. These prospects point to the necessity of sustained innovation and further research for utilising the potentials in animation as a teaching aid in science education.

Animated computer material in science education has to be considered an aid but nothing that can guarantee an understanding of scientific concepts. Results from the studies clearly demonstrate that there are no straightforward ways in learners' understanding of the phenomena described by the digital learning application. The studies do not give support for the assumption that an animated description, as such, enhances understanding of scientific concepts. On the contrary, it is indicated that animated models of scientific concepts risk inferring misconceptions if students are left on their own with interpreting information from the learning material. This emphasises that animated learning material cannot function as a 'stand alone' educational tool. Therefore, when applying digital learning material for educational purposes one have to consider a wider context where task formulation, teacher guidance, school culture and semiotic processes influence how students approach and frame their assignment of construing the described events.

References

Ametller, J., & Pint´o, R. (2002). Students' reading of innovative images of energy at secondary school level. *International Journal of Science Education, 24*(3), 285- 312.

Atkinson, M. J., & Heritage, J. C. (1984). *Structures of social action: Studies in conversation analysis*. Cambridge: Cambridge University Press.

Bereiter, C. (2002). Design research for sustained innovation. *Cognitive studies, Bulletin of the Japanese Cognitive Science Society, 9*(3), 321-327.

Bergqvist, K. (1990). *Doing schoolwork: Task premises and joint activity in the comprehensive classroom*. Linköping, Sweden: Department of Communication Studies, Linköping University.

Biesta, G. (2007). Why "what works" won't work: Evidence-based practice and the democratic deficit in educational research. *Educational Theory, 57*(1).

Boz, Y. (2006). Turkish Pupils' Conceptions of the Particulate Nature of Matter. *Journal of Science Education and Technology, 15*(2), 203-213.

Brown, A. L. (1992). Design experiments: Theoretical and Methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141-178.

Bruner, J. (1977). *The process of education*. Cambridge, Mass: Harvard University Press.

Bruner, J. (1996). *The culture of education*. Cambridge: Harvard university press.

ChanLin, L.-J. (1998). Animation to teach students of different knowledge levels. *Journal of Instructional Psychology, 25*(3), 166-176.

Chittleborougha, G. D., Treagusta, D. F., Mamialab, T. L., & Mocerinoa, M. (2005). Students' perceptions of the role of models in the process of science and in the process of learning. *Research in Science & Technological Education, 23* (2), 195-212.

Collective, D.-B. R. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8.

Crook, C. (1994). *Computers and the collaborative experience of learning*. London and New York: Routledge.

Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. New York: Teachers College Press.

Davies, P. (1999). What Is Evidence-Based Education? *British Journal of Educational Studies, 47*(2), 108-121.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Dewey, J. (1916). *Democracy and education*. New York: MacMillan.

Eriksson-Zetterquist, U., Hansson, H., Löfström, M., Ohlsson, Ö., & Selander, M. (2006). *Ett möte med förhinder, om IT-satsningar i skolan. Göteborg, Sweden: BAS, Handelshögskolan*.

Fillmore, C. J. (1968). The case for case. In E. Bach & R. T. Harms (Eds.), *Universals in linguistic theory*. N Y: Holt, Rinehart and Winston, Inc.

Gabel, D. L. (1998). The complexity of chemistry and implication for teaching. In B. J. Fraser & T. K.G (Eds.), *International handbook of science education* (pp. 233- 248). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Garfinkel, H. (1967). *Studies in ethnomethodology*. NJ: Prentice-Hall.

Garfinkel, H. (1988). Evidence for Locally Produced, Naturally Accountable Phenomena of Order, Logic, Reason, Meaning, Method, etc. In and as of the Essential Quiddity of Immortal Ordinary Society, (I of IV): An Announcement of Studies. *Sociological Theory, 6*(1), 103-109.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Glasersfeld, E. v. (1995). *Radical Constructivism: A way of Knowing and Learning*. New York: Routledge Falmer.

Goldman, R., Pea, R., Barron, B., & Derry, S. (2007). *Video research in the learning sciences*. Mahwah, NJ: Lawrence Erlbaum Associates.

Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of Pragmatics, 32*, 1489-1522.

Goodwin, C. (2001). Practices of Seeing, Visual Analysis: An Ethnomethodological Approach. In T. van Leeuwen & C. Jewitt (Eds.), *Handbook of Visual Analysis*. London: Sage.

Greeno, J. G. (1989). A perspective of thinking. *American Psychologist, 44*(2), 134-141.

Greiffenhagen, C., & Watson, R. (2007). Visual Repairables: analyzing the work of repair in human-computer interaction. *Forthcoming in Visual Communication*.

Grosslight, L., Unger, J., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Hakkarainen, K. (2003). Progressive Inquiry in a Computer-Supported Biology Class. *Journal of research in science teaching, 40*(10), 1072-1088.

Halliday, M. A. K. (2004). *The language of science*. London: MPG Books Ltd.

Han, J., & Roth, W.-M. (2006). Chemical inscriptions in Korean textbooks: Semiotics of macro and microworld. *Science education, 90*(2), 173-201.

Hennessey, S., Wishart, J., Whitelock, D., Deany, R., Brawn, R., la Velle, L., et al. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers and Education, 48*, 137-152.

Ivarsson, J. (2003). Kids in zen: Computer-supported learning environments and illusory intersubjectivity. *Education, Communication & Information, 3*(3), 383-402.

Ivarsson, J. (2004). *Renderings & reasoning: studying artifacts in human knowing.* Gothenburg University, Göteborg.

Ivarsson, J. (in press). Developing the construction sight: Architectural education and technological change. *Visual Communication, 9*(4).

Jansson, I., Andersson, B., & Emanuelsson, J. (1994). *Gymnasieelevers kunskaper om ekologi och människokroppen*. Göteborg: Göteborgs Universitet, Institutionen för ämnesdidaktik.

Jonassen, D. (Ed.). (1999). *Designing constructivist learning environments*. Mahwah, NJ: Lawrence Erlbaum Associates.

Jonassen, D., Kyle, L., & Brent, G. (1999). *Learning with technology, a constrictivist perspective*. Upper Saddle river, NJ: Prentice Hall, Inc.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Science*, *4*(1), 39-103.

Karlsohn, T. (2009). *Teknik - Kritik - Retorik. Om IT-bubblan och datoriseringen av den svenska skolan*. Stockholm: Carlssons.

KK-stiftelsen (2006). *IT i skolan: Attityder, tillgång och användning*: http://www.kks.se/upload/publikationsfiler/it_i_utbildning/it_i_skolan_2006_2006_publ.pdf.

Klein, J. D., & Doran, M. S. (1999). Implementing Individual and Small Group Learning Structures with a Computer Simulation. *Educational Technology Research and Development*, *47*(1), 97-110.

Koschmann, T., Stahl, G., & Zemel, A. (2007). The video analyst's manifesto (or the implications of Garfinkel's policies for studying instructional practice in design-based research). In R. Goldman, R. Pea, B. Barron, S. J. & S. Derry (Eds.), *Video research in the learning sciences*. NJ: Routledge

Kozma, R. (2003). *Technology innovation and educational change: A global perspective*. Oregon: International Society for Technology in Education (ISTE).

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: expert and novice responses to different representations of chemical phenomena. *Journal of research in science teaching 34*(9), 949-968.

Krange, I., & Ludvigsen, S. (2008). What does it mean? Students' procedural and conceptual problem solving in a CSCL environment designed within the field of science education. *International Journal of Computer-Supported Collaborative Learning, 3,* 25-51.

Kumpulainen, K., & Mutanen, M. (1999). The situated dynamics of peer group interaction: an introduction to an analytic framework. *Learning and Instruction, 9*(5), 449-473.

Lagemann (2000). *An elusive science: The troubling history of education research*. Chicgo: The University of Chicago Press.

Lantz-Andersson, A. (2009). *Framing in Educational Practices: Learning Activity, Digital Technology and the Logic of Situated Action.* Gothenburg University, Göteborg.

Laurier, E., & Philo, C. (2006). Natural Problems of Naturalistic Video Data. In H. Knoblauch, B. Schnettler, J. Raab & H.-G. Soeffner (Eds.), *Video Analysis: Methodology and Methods*. Frankfurt am Main: Peter Lang.

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate peripheral participation*. Cambridge: University Press.

Lemke, J. L. (1990). *Talking science—Language, leaning, and values*. London: Ablex.

Lemke, J. L. (1998). Analysing verbal data: Principles, methods, and problems. In K. Tobin & B. Fraser (Eds.), *International Handbook of science education* (pp. 1175-1189). Boston: Kluwer.

Lemke, J. L. (2006). Towards critical multimedia literacy: technology, research, and politics. In M. McKenna, L. Labbo, R. Keiffer & D. Reinking (Eds.), *Handbook of Literacy and Technology* (Vol. 2, pp. 3-14). N Y: Erlbaum (LEA Publishing).

Lindwall, O. (2008). *Lab work in science education*. Linköping: Linköping Universtiy.

Lofgren, L., & Hellden, G. (2008). Following Young Students' Understanding of Three Phenomena in which Transformations of Matter Occur *International Journal of Science and Mathematics Education, 6*(3), 481-504.

Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. *European Journal of Psychology of Education, 14*(2), 225-244.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction, 13,* 157-176.

Lowe, R. K. (2004). Interrogation of a dynamic visualization during learning. *Learning and Instruction, 14*(3), 257-274.

Lund, A., & Rasmussen, I. (2008). The right tool for the wrong task? Match and mismatch between first and second stimulus in double stimulation. *International Journal of Computer-Supported Collaborative Learning, 3*(4), 387-412.

Mayer, R. E. (1997). Multimedia learning: are we asking the right questions? *Educational Psychologist, 32*, 1-19.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge: Cambridge University Press.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When Static Media Promote Active Learning: Annotated Illustrations Versus Narrated Animations in Multimedia Instruction. *Journal of Experimental Psychology: Applied, 11*(4), 256-265.

Mayer, R. E., & Moreno, R. (2002). Animation as an aid to multimedia learning. *Educational Psychology Review, 14*(1), 87-99.

McCloud, S. (1994). *Understanding Comics. The invisible art*. New York: HarperPerennial.

Mikropoulos, T. A., Katsikis, A., Nikolou, E., & Tsakalis, P. (2003). Virtual environments in biology teaching. *Journal of Biological Education, 37*, 176-181.

Mondada, L. (2003). Working with video: how surgeons produce video records of their actions. *Visual Studies, 18*(1), 58-73.

Mondada , L. (2006). Participants' online analysis and multimodal practices: projecting the end of the turn and the closing of the sequence. *Discourse Studies, 8*(1), 117-129.

Mulder, I., & Swaak, J. (2002). Assessing group learning and shared understanding in technology-mediated interaction. *Educational Technology & Society, 5*(1).

Nishizaka, A. (2000). Seeing what one sees: perception, emotion, and activity. *Mind, culture, and activity, 7*(1&2), 105-123.

Petraglia, J. (1998). *Reality by design: The rhetoric and technology of authenticity in education*. Mawahah, NJ: Lawrence Erlbaum Associates.

Piaget, J. (1929/1975). *The Child's Conception of the World*. Boston: Lanham, MD (Originalarbete översatt från franska 1929).

Rebetez, C., Bétrancourt, M., Sangin, M., & Dillenbourg, P. (2008). Learning from animations enabled by collaboration. *Instructional Sciences (in press)*.

Riis, U. (2000). *IT i skolan mellan vision och praktik: En forsknings-översikt*. Kalmar: Skolverket.

Riis, U., & Jedeskog, G. (1997). *Pedagogik, teknik eller ekonomi: En baslinjebestämning av KK-stiftelsens kommunbaserade skolutvecklingsprojekt*. Uppsala: Uppsala Universitet.

Roth, W.-M. (2001). Situating cognition. *The journal of the learning sciences, 10,* 27-61.

Roth, W.-M., & Lee, Y.-J. (2006). Computers and cognitive development at work. *Educational Media International, 43*(4), 331-346.

Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997). The local production of order in traditional science laboratories: A phenomenological analysis *Learning and Instruction, 7,* 107-136.

Roth, W.-M., Woszczyna, C., & Smith, G. (1996). Affordances and Constraints of Computers in Science Education. *JOURNAL OF RESEARCH IN SCIENCE TEACHING, 33*(9), 995-1017.

Russell, T. L. (1999). *The no significant difference phenomenon (5th ed.)*. Montgomery: International Distance Education Certification Center.

Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). Simplest systematics for the organization of turn-taking for conversation. *Language, 50*, 696-735.

Schegloff, E. A. (1991). Conversation analysis and socially shared cognition. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 150-171). Washington DC: APA.

Schegloff, E. A., Jefferson, G., & Sacks, H. (1977). The preference for selfcorrection in the organization of repair in conversation. *Language*, *53*(2), 361-382.

Schnotz, W., Böckheler, J., & Grzondziel, H. (1999). Individual and co-operativ learning with interactive animated pictures. *European Journal of Psychology of Education, 14*, 245-265.

Schnotz, W., & Rasch, T. (2005). Enabling, facilitating, and inhibiting effects of animation in multimedia learning: Why reduction of cognitive load can have negative results on learning *Educational Technology Research and Development.*, *53*(3), 47-58.

Schrum, L., Thompson, A., Sprague, D., Maddux, C., McAnear, A., Bell, L., et al. (2005). Advancing the field: Considering acceptable evidence in educational

technology research. *Contemporary Issues in Technology and Teacher Education*, *5*(3/4), 202-209.

Slotta, J. (2002). Designing the "Web-Based Inquiry Science Environment (WISE).". *Educational Technology*, *42*(5), 15-20.

Snir, J., Smith, C. L., & Raz, G. (2003). Linking phenomena with competing underlying models: A software tool for introducing students to the particulate model of matter. *Science Education, 87*(6), 794- 830.

Spindler, G., & Spindler, L. (1992). Cultural process and ethnography: an anthropological perspective. In M. D. L. a. J. Preissle (Ed.), *The handbook of qualitative research in education*. London/New York: Academic Press.

Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis. *Review of Educational Research, 69*(1), 21-51.

Stahl, G. (2002). Rediscovering CSCL. In T. Koschmann, R. Hall & N. Miyake (Eds.), *CSCL 2: Carrying forward the conversation* (pp. 169-181). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stahl, G. (2006). *Group cognition: computer support for collaborative knowledge building*. Cambridge: MIT press.

Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409-426). Cambridge: Cambridge University Press.

Stavy, R. (1988). Children's Conception of Gas. *International Journal of Science Education, 10*(5), 553-560

Stavy, R. (1990). Children’s conception of changes in the state of matter: from liquid (or solid) to gas. *Journal of Research in Science Teaching, 27*(3), 247-266.

Stylianidou, F., Ormerod, F., & Ogborn, J. (2002). Analysis of science textbook pictures about energy and pupils’ readings of them. *International Journal of Science Education, 24*(3), 257- 283.

Säljö, R. (1998). Thinking with and through artifacts: The role of psychological tools and physical artifacts in human learning and cognition. . In D. Faulkner, K. Littleton & M. Woodhead (Eds.), *Learning relationships in the classroom*. London: Routledge.

Säljö, R. (2000). *Lärande i praktiken: Ett sociokulturellt perspektiv. [Learning in practice: A sociocultural perspective]*. Stockholm, Sweden: Prisma.

Säljö, R. (2004). Learning and technologies, people and tools in coordinated activities. *International Journal of Educational Research, 41*(6), 489-494.

Säljö, R., & Linderoth, J. (2002). *Utm@ningar och e-frestelser: IT och skolans lärkultur*. Stockholm: Prisma.

Teasley, S. D., & Roschelle, J. (1998). Constructing a Joint Problem Space: The Computer as a Tool for Sharing Knowledge. Retrieved from http://ctl.sri.com/publications/downloads/JointProblemSpace.pdf

Tomlin, R. S. (1997). Mapping conceptual representations into linguistic representations: The role of attention in grammar. In J. Nuyts & E. Pedersen (Eds.), *Language and conceptualization* (pp. 162-189). Cambridge: Cambridge University Press.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*, 247-262.

Wells, G. (1999). *Dialogic inquiry: Toward a sociocultural practice and theory of education*. Cambridge, MA: Cambridge University Press.

Wertsch, J. V. (1991). *Voices of the mind. A sociocultural approach to mediated action*. Cambridge, MA: Harvard University Press.

Vygotsky, L. (1930/1978). *Mind in society*. Cambridge, MA: Harvard University Press

Vygotsky, L. (1934/1986). *Thought and language*. Cambridge, MA: The MIT Press.

Study I

Animations in science education

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ABSTRACT

The overall aim of this chapter is to explore some of the pedagogical potentials, as well as limitations, of animations displaying complex biochemical processes. As the first part of our larger research project, a learning environment was developed where visualisations by means of 3-D animations depicted some of the processes in the carbon cycle. In the analysis we describe how three groups of students made use of and reasoned about the computer animations. In relation to the aim, three salient themes are discernible in the video material of the students' reasoning; the risk of focusing the attention on misleading aspects of the animation, the possible occurrence of a form of isolated reasoning, and, the students' varying understandings of what resources they are expected to use when performing a given task.

INTRODUCTION

Misconceptions are one of the grand themes of educational research in general and science education in particular. Students' misconceptions of various scientific principles are recurrent topics in numerous studies, in for instance physics (D. E. Brown, 1992; Jones, 1991), biology (C. R. Brown, 1990; Odom, 1995) chemistry (Goh, 1993; Nicoll, 2001; Sanger & Greenbowe, 1999). The means to meet the educational challenges spelled out by educators and educational researchers has obviously varied, but throughout the twentieth century, the use of technological innovations has been an increasingly frequent strategy (Petraglia, 1998a, 1998b).

For higher biology and medical education several digital applications have been developed. Camp, Cameron and Robb (1998) created virtual 3-D simulations enabling medical students to examine anatomic models and Karr and Brady (2000) describes interactive 3-D technologies for teaching biology. Virtual learning environments for primary school (Mikropouls, Katsikis, Nikolou, & Tsakalis, 2003) and high school (Kameas, Mikropoulos, Katsikis, & Pintelas, 2000) have been developed and in some respect been tested out and evaluated.

Given all the time and effort invested in these matters, however, positive and stable results from the use of educational technologies are remarkably few. To underscore this observation we would like to point to a claim by

Euler and Müller (1999) who hold that, within the area physics education, the technology known as *probeware* is the *only* computer-based learning environment that has a proven general positive learning effect. Adding to the picture, that, the area of physics education is intensely studied, renders the remark by Euler and Müller even more conspicuous. Thus, as a general pattern, students seem to be invariably immune to any simple technological treatments; despite whatever new technologies we introduce into our educational systems, *learning* continues to be a struggle for educators and students alike.

In spite of this rather gloomy outlook, ever-new items are added to the list of possible remedies of educational dilemmas and student difficulties. One item on this list, and the topic of the current chapter, is the use of *animations* as educational resources. Our specific field of investigation concerns secondary school science education and the aim is to analyse the reasoning students perform when working with animated sequences of the carbon cycle.

THE CARBON CYCLE AS A TOPIC FOR EDUCATION

One of the main topics in curricula for primary and secondary schools for education of natural science is the carbon cycle and its vital importance for conditions concerning life on earth. Studies of the two main processes in the carbon cycle, photosynthesis (Barak, Sheva, & Gorodetsky, 1999; Cañal, 1999; Eisen & Stavy, 1993) and respiration (Sanders, 1993; Seymour & Longden, 1991; Songer & Mintzes, 1994) report that students' knowledge of these gaseous processes is poorly understood and that misconceptions are frequent. In consideration of the utilisation of fossil fuel and the ensuing global warming, combustion is another process in the carbon cycle deemed increasingly important. This process is chemically equal to the respiration with the exception that it is not a cellular process.

A major problem with the conceptualisation of the processes in the carbon cycle is that they involve gaseous forms that are not directly observable and therefore have to be grasped trough some representational system. The traditional textbooks most often illustrate the carbon cycle in pictures furnished with arrows describing the course of the circulating material. Given an educational framing, one could conclude that there should be potential gains from developing educational material that builds on more dynamic forms of representations, e.g. computer animations. From a research perspective, however, this still remains an open question. Before turning to the specific but still problematic question on the animation of the carbon cycle, we will briefly discuss recent work done on the use of different animations in education.

COMPUTER ANIMATIONS IN EDUCATION

The scientific results emanating from research exploring the educational value of animated graphics – as compared to the use of its static counterparts – are hitherto inconsistent. The research results display a complex and confusing array of outcomes in different educational settings. From an initial euphoria over the vast educational possibilities associated with multimedia technologies, a more composed picture is now emerging. However, the expectations of multimedia in educational settings, although somewhat moderated, still exist and call for further research in the area.

Based on a series of studies, Mayer (1997) argues to have found consistent support for a generative theory of multimedia learning, and offers the explanation that coordinated presentation of explanatory words and pictures is effective because it helps guide students' cognitive processes. In addition, he demonstrates what he calls a contiguity effect when visual and verbal information is presented closely together. For the prospects of computer-based learning he concludes: "In computer-based multimedia learning environments students have the opportunity to work easily with both visual and verbal representations of complex systems, but to fruitfully develop these potential educational opportunities, research is needed on how people learn with multimedia" (p. 17). Most investigations comparing the learning outcomes of students' work with animated versus static pictures however, have not been able to show any enhanced learning efficacy brought by the animations. The results rather indicate the contrary. In a comprehensive research review Tversky, Morrison and Betrancourt (2002) could not find evidence supporting the view that animations are superior to the use of static graphics in education. Lowe (1999; 2003) suggests, that merely providing an accurate animated depiction of the to-be-learned material may not in itself be sufficient to produce the desired outcome. In his studies of how meteorological novices worked with animated weather maps, the extraction of information appeared to be largely driven by perceptual characteristics of the display. Students unfamiliar with the depicted subject matter tended to extract information about components of the animation with characteristics such as structural coherence, distinctive appearance and dynamic change more readily than they extracted information about components lacking these qualities. Retention also seemed more likely for those aspects of the dynamic graphics that were relatively easy to extract. This extraction and retention of the most perceptual salient characteristics of animations, irrespective of their relevance with regard to the intended subject matter, is something one has to take into account when designing educational animations. Lowe (2003) also concludes that the problem appeared to stem from lack of explicit information about the relative importance of various aspects of the animation and he conjectures that students could be helped by providing the learning environment with specific visual and temporal guidance. Consequently, he proposes that further research is needed to determine if these findings can be generalised and how the animations might be manipulated in order to modulate the way in which students' attention is distributed between features that differ in their intrinsic perceptibility.

Mayer, Hegarty, Mayer and Campbell (2005) made four experiments comparing the learning outcomes of the use of computer-based animations and narration versus paper-based static diagrams and text. Based on these experiments the authors argue that static presentations containing illustrations and printed text can be superior to dynamic presentations containing narrated animation. Their reasoning is further given a theoretical framing, from within which static media is seen as having the advantage of engaging people in less extraneous cognitive processing. By that line of reasoning, one is therefore able to engage in deeper cognitive processing when learning from static illustrations and text, as compared to dynamic animations and commentaries. On the other hand, Mayer et al. (2005) remark that their study should not be interpreted as if animations are ineffective in all situations. For example, animations are said to improve understanding for learners with limitations in spatial ability, or, when they are used to visualise processes that are not visible in the real world.

When comparing individual and collaborative learning with interactive animated pictures versus static ones, Schnotz, Böckheler, & Grzondziel (1999) found that animated pictures could result in better learning about dynamic subjects for individual learners but lead to lower learning results in collaborative learning. They attribute their results to the effect that collaborative learners have to devote a substantial proportion of their cognitive processing capacity to both operating the visual presentation and coordinating their learning activity with those of their partner. In accordance with this view, learners working collaboratively would have less cognitive resources available for processing the learning content. However, conflicting results are presented by Rebetez, Sangin, Bétrancourt and Dillenbourg (2005) who demonstrate a positive effect of animated graphics over static ones for students learning in pairs compared to individual learners. These authors interpret their results by the *underwhelming effect* described by Lowe (2003): participants working on their own were less active because they simply had to attend to the animation and not to build a shared representation of the animation with a partner leading to the illusion of comprehension. In summary, both studies referred to above explored computer animations, and, compared students working individually to students working in pairs, but they come to contradicting conclusions. One possible explanation is that the learning conditions were quite different in the two studies. For example, Schnotz et al. (1999) used interactive animated pictures while the participants in the study by Rebetez et al. (2005) had no control over the presentation. In relation to this, we hold that there is a need to consider the educational setting, in which animations are used, for understanding the learning outcome.

Under the auspices of cognitive load theory, another factor thought influencing the learning outcome when using animations is the students' learning prerequisites. Animated pictures are regarded as having a facilitating function insofar as they allow an external simulation process that makes an alleged corresponding mental simulation less demanding (Schnotz & Rasch, 2005). Accordingly, this is seen as beneficial for learners who would not be able to perform this operation without external support, but, on the other hand, as harmful to learners who could perform the mental simulation on their own. In the latter case, the authors argue, the animation reduces the cognitive load but also reduces germane load that is necessary for learning. Schnotz and Rasch conclude that, "The use of animation in multimedia learning environments seems to be beneficial only under some circumstances, whereas it can have negative effects under other circumstances." (2005, p. 57)

What advantages can an interactive computer animation entail in comparison with, for example, viewing a film illustrating the same process? By breaking down an animated presentation into short segments Mayer (2001) showed that students who were able to control the presentation pace — by clicking on a button to receive each of the segments — performed better on transfer tests than did students who viewed the entire presentation as a continuous unit. Thus, it seems as if this form of interactivity can help overcome some of the difficulties of perception and comprehension associated with animations. As argued by Tversky et al. (2002), simply enabling the starting, stopping and replaying of an animation will allow for re-inspection and facilitates the user to focus on specific parts and events.

The interest for computer games is considerable among the youth today and many students are therefore familiar with virtual environments of this kind. Among educators there have been recurring attempts to buy one's way into the success of the gaming industry by adopting part of its format. One example is the Viten project which has its roots in WISE[1] (developed by the WISE-project at the University of California, Berkeley). Like WISE, the Viten project is free and open software[2], enabling science teachers to use web-based science curriculum materials. It presents programs combining text, simulations and animations in topics of science and mathematics. In the most popular Viten program – 'Radioactivity' – the interactive animations and other features are described to contribute to student learning by making the 'invisible' visible (Mork, 2005). When summarising students' positive comments, Mork (2005) identifies a number of categories which are thought to provide some general insights about what is appreciated in a teaching sequence, i.e.: using computers, variation, informative materials, working together, and student control. On the one hand, these are key words to have in mind when planning any teaching sequence or when developing new learning materials. On the other hand, they are also very general descriptions, too abstract in order to provide any substantial insights, and, every such term must therefore be disambiguated and given a specific content on every new occasion and in every new educational design (Lindwall & Ivarsson, 2004, in press).

AIM OF THE STUDY

So far, studies of the educational use of animations have mainly been concentrating on the learning outcomes in quantitative terms. In this study, we analyse the reasoning and interaction taking place when groups of students collaborate in connection to a set of animations. Interaction analyses of knowledge building in small groups is an emerging and important methodology in the area of computer supported collaborative learning (CSCL) (Stahl, 2006). Arguably, the better we understand the students' collaborative reasoning on a given topic, the better we can design specialist computer support, and, the surrounding learning environment in which this support is intended to serve. Evaluating new educational set-ups also raises the problem of how technology interacts with the students' emerging conceptualisa-

[1] Available at http://wise.berkeley.edu

[2] Available at http://viten.no

tions. By analysing the students' interaction and talk we aspire to gain insights into their interpretations of the depicted phenomena.

The overall aim of this study is to explore some of the pedagogical potentials, as well as limitations, of animations displaying complex biochemical processes. As the first part of our larger research project, a learning environment was developed where visualisations by means of animations depicted some of the processes in the carbon cycle. In the analysis we describe how the students made use of and reasoned about the computer animations.

APPLICATION DESIGN

The background and motive of developing a sequence of computer animations can be found in the educational situation of the specific subject matter: the carbon cycle. As already alluded to, the teaching of this topic could, as seen from the science teacher point of view, potentially benefit from having an educational material that build on dynamic forms of representations.

Figure 1. The index page from where you navigate among the animations of the processes in the carbon atom cycle

The intention informing the design was to make the illustrations in the graphics as concrete as possible and to concentrate on just one event in every sequence. Software for production of 3-D animations was used for the development of the pedagogical application[3]. The index page (see Figure 1) contains a text describing the main outlines of the carbon atom cycle. To the left there is a menu with links to the different pages in the application. At the bottom there is a row of clickable miniatures that links to the different animations. The pages describe the different processes of photosynthesis, breathing, combustion and mouldering. Each page has an explanatory text which was kept as concise as possible not to be considered too tiresome to be read by the students. Underneath the captions there is a miniature image linking to the animations. The program allows for some limited interactivity as the students only can start and stop the animated sequences.

Photosynthesis is illustrated in three animated sequences. The three sequences in various ways illustrate carbon dioxide molecules diffusing into the leaves of a tree, the building up of the foliage and oxygen molecules emitting from the leaves.

Breathing is illustrated by the human lungs in section. The animation shows how oxygen, which is taken in through the respiratory passages, is exchanged for carbon dioxide that is exhaled. Since the breathing is an active process the animation gives a reasonably correct picture of the actual process. However, the cellular respiratory process and gas transportation with the blood are not shown in the animation. Furthermore, the animation displays the inhalation air by means of only oxygen molecules, and similarly, only the carbon dioxides are represented in the exhalation air. In reality there is a mix of gases in both the inhalation and exhalation air where oxygen and carbon dioxide constitute a minor part and where only the proportion of these gases differs. Thus the animation constitutes a considerable simplification of the real events.

Mouldering and *combustion* are illustrated by a mouldering log and a log fire respectively. The wood is used for making the connection easier be-

[3] The application is available at: http://www.init.ituniv.se/~gorkar /

tween the photosynthesising tree and the mouldering or burning tree. In the animation of both mouldering and combustion, one will see oxygen molecules coming in from the side and carbon dioxide molecules leaving the log and the log fire respectively in an upward direction. Again this is a simplified and schematic illustration of indiscernible and passive gas exchanges and it does not show the actual processes occurring inside the wood.

In conclusion, common to all animations is that they focus on the movements of the gaseous molecules oxygen (O_2) and carbon dioxide (CO_2) in the different depicted processes. It should be noted that, as the animations are designed to emphasise these relations, this form of highlighting (Goodwin, 1994) simultaneously runs the risk of concealing other important molecular reactions. The relation between possible advantages and drawbacks connected to the use of this form of representation constitutes a major part of the empirical study and it is this issue that we will address in the analysis.

RESEARCH DESIGN

A total of 40 students attending a science course in a Swedish secondary school took part in the study. The 16 girls and 24 boys were grouped into dyads or triads, totalling 19 groups, thus allowing peer discussions and engaging the students in reflection and comparing their different views with each other. The study was conducted during a 1.5-hour study session for each group.

Before starting their exploration of the animations the students were given a short instruction about how to manage and navigate within the learning environment. There was no tutorial introduction of the topic but the students had the opportunity to consult their teacher during the learning session. The students also got an explanation of what a model of a phenomenon means. It was stressed that when using simulations as models for real phenomena the students must not mistake a simulation for the actual phenomena (cf. Flick & Bell, 2000). For about 20 minutes the students worked with the animations. During this time they were given the task of writing down what they saw happening in the different sequences. After that, while still having access to the animations, they were assigned to discuss and jointly describe what was happening in the carbon cycle.

To gain an understanding of how the students interpreted their tasks and reasoned about the animations, three groups were randomly selected and videotaped during the entire session. The analysis builds on the work of these three groups. This analysis, of the students' interaction with each other and with the technology, draws on an analytic tradition which Jordan and Henderson (1995) summarises under the label *interaction analysis*. Like the authors, we find this interdisciplinary method for the empirical investigation of human activity, particularly helpful in complex, multi-actor, technology-mediated work settings and learning environments. Through the detailed analysis of videotaped material, this method tries to describe the ways participants orchestrate both communicative and material resources when performing any given task (Ivarsson, 2004).

RESULTS

In relation to the aim of understanding the pedagogical workings of the specific animations displaying complex biochemical processes, three salient themes are discernible in the video material of the students reasoning. The first concerns the risk of focusing the attention on misleading aspects of the animation, a problem in some respect related to the design of the technology. A second problem observed is the possible occurrence of a form of isolated reasoning, seemingly connected to the simplified nature of the representations. The last observed problem is the students' varying understanding of what resources they are expected to use when performing a given task.

Misguided Attention

As the animations are mere models of unobservable molecular processes, the interpretations of these representations can result in several misleading inferences. One example of such a misleading feature of the animation – not really belonging to the model – is observable in the excerpt below where three students are watching the animation of gaseous exchange by a photosynthesising tree.

Veronica: now you see what is happening, what happens

Henric: ok, carbon dioxide molecule gets stuck, in the tree

Veronica: in the tree and oxygen, oxygen

Henric: oxygen carb-eh-molecule

Veronica came out

Henric blows away

Veronica is asking Henric what happens in the animation. Henric explains what he observes with a mix between scientific designations and everyday expressions like 'gets stuck, in the tree' and 'blows away'. These specific wordings are later adopted by Veronica, as shown in the next excerpt.

Veronica: there we shall write the first picture shows that oxy carbon dioxide or what- ever it's called gets stuck in the tree and oxy blah-blah, blows away as he said

Henric: ok, the tree catches oxygen molecules through blowing or something like that it stays so the oxygen keeps on blowing

Veronica remarks that carbon dioxide 'gets stuck' and oxygen 'blows away', thereby referring to Henric's earlier utterance. Henric makes no distinction between the two kinds of molecules and does not comment on the assimilation of carbon dioxide. His remark about 'blowing or something like that' could indicate an uncertainty about the blowing as the driving force for the molecules. However, when subsequently asked by the teacher what is shown in the animation, he reiterates and reinforces the narrative about the 'blowing' that makes 'the tree catches oxygen molecules'.

Teacher: yes what is happening here?

Henric: yes we only saw oxygen molecules and by means of blowing it gets stuck

Veronica: ((clicks at the icon showing the photo synthesis)) look there-what's coming

Teacher: yes look what's coming here, what is it that gets stuck

Henric responds to the teacher's question by focusing on the perceptual salient feature of the oxygen molecules as moving in one direction. In his words, this 'blowing' is the cause that makes the molecules 'get stuck' in the leaf. Veronica refers to the carbon molecules as something that is 'coming there.' This particular way of talking about the depicted processes is not corrected by the teacher, not in this excerpt nor in the subsequent discussion with the group. Instead the teacher repeats the somewhat misleading characteristics of molecules as ‘coming’ and ‘getting stuck’ and tries to focus the student’s attention on the actual molecules.

Isolated Reasoning

The animations show only limited parts of the complex biochemical processes occurring inside organic material. This is an inevitable feature of any model. But, the interesting question is whether the limit of scope functions differently with an animation as compared to a static picture. The observations in the next two excerpts do indicate something in that direction.

Said: ((reads from the questionnaire)) the following questions you can discuss with a peer and write down which conclusion you have reached, one- we breathe in oxygen and breathe out carbon dioxide, from where do the carbon atoms in the carbon dioxide that we breathe out come from (3 s) uhm yeah we breathe in oxygen and like from where do the carbon atoms in carbon dioxide that we breath out come from

Kevin: yeah that’s you know from pollution

Said: carb- carb- the carbon atoms

Kevin: isn’t it from pollution from the car and things

Said: no I don’t know

Kevin: ‘cause we don’t breathe in 100% oxygen

Said: then from where come the carbon atoms in the carbon dioxide that we breathe out hmm (6 s) yea then isn’t it so that when we breathe in then we like take when we breathe out then it becomes carbon dioxide it means that (2 s) it has to come from our lungs then

Kevin: yes

Said: where they sort of are cleaned or some cycle in our lungs like

Kevin: from where do they come, are they from, we don’t breathe in 100 % oxygen do you understand what I mean?

Said: yes ((watching the animation showing breathing))

Kevin: then (2 s) they probably come from (3 s) exhaust pipes from cars and such

Said: I think so too

The animated sequence that the students have recently watched is making visible the processes of inhalation and exhalation and thereby focuses on the two different gases (oxygen and carbon dioxide). Similarly, the dialogue between the two boys takes its starting point from the assumption that the carbon atoms originate from an airborne external source and reach our lungs through the inhalation air. In their discussion they stick to this rationale and endeavour to conceive of a source emitting carbon atoms into the air. As we can observe, their discussion is completely concentrated on a circulation of the carbon atoms inside the lungs. In one sense, this is an adequate way of reasoning, since the animation of the breathing is only visualising the gas exchange in the lungs. Presumably they did not read the caption explaining the metabolism, thereby restricting the external input of their reasoning to the limited view that was given by the animation. The reading of the text was not expressed in their task and this group did follow the instruction, which was to discuss with a peer what they could observe and thereafter write down their conclusion. In this case, this obviously led them to an erroneous conclusion, which could possibly have been avoided if they had been encouraged to read the text captioning the breathing animation.

Another example of this somewhat isolated reasoning, and misleading inferences due to limitations of the animation, is demonstrated in the excerpt below. Here, two girls are watching and discussing what happens in the animation illustrating the combustion by a burning log fire.

Gloria: oxygen comes in

Petra: and out,

Gloria: comes carbon dioxide

Petra: so oxygen is necessary for the fire to burn and out then just like in the human body when the oxygen is consumed carbon dioxide comes out

Gloria: carbon dioxide comes out

Petra: does that sound probable?

Gloria: that sounds very sensible in some way

Petra: you know from you were playing with candles when you were little when you put a glass over it takes a while before it goes out

Gloria: yeah (7 s)

Petra: but to make something burn you have to have some material that can burn

Petra: but that's what you- that would be the oxygen then

Gloria: yes in principle

In the beginning of this discussion, Petra displays a very knowledgeable reasoning about the requirement for oxygen in the combustion, referring to the experience of putting a glass over a candle. She then remarks on the necessity of having some burning material. Gloria suggests that this would be oxygen, whereupon Petra agrees with her. Coming to the erroneous conclusion that oxygen is the burning material can be a quite understandable consequence if only watching the animation. Here the oxygen molecules can be seen moving into the log fire and the carbon dioxide molecules leaving whereas the firewood remains unaltered. Consequently the animation offers no way of discerning the chemical process actually taking place during combustion.

The animations, as mentioned above, are intended to focus on specific relations in the biochemical processes, and, they thereby necessarily downplay, or hide, other potentially relevant aspects. Here we have two examples where this seems to become a pedagogical problem. The fact that something very specific is highlighted by the animation could also indicate that one has a harder time breaking out of that offered frame. In this way, the learning environment invites to way of reasoning that, at times, becomes isolated in relation to the overall topic (for a similar discussion see Ivarsson, 2003).

Conflicting Perspectives

The students' first task was to describe what they could observe in the animations. When analysing the reasoning of the students, this seemingly easy instruction opens into a complex task that holds two conflicting perspectives. In the excerpt below, Petra and Gloria are discussing the animation of breathing.

Petra: ((Clicks on Breathing in the menu and both girls read the text about breathing)) (29) are we ready?

Gloria: yeah

Petra: oxygen

Gloria: oxygen you breathe in so you breathe out carbon dioxide

Petra: carbon dioxide they transform there

Gloria: they transform in the lungs

Petra: it must be

Petra: yes ((makes notes)) (28 s)

Gloria: but really it's not like that, that they come in and become carbon dioxide when you breathe out but it's about oxygen coming in, and going out into the cells

Petra: ah

Gloria: and then they take it up

Petra: but what you see in the animation

Gloria: in the animation it is that then you see that oxygen comes into the lungs and carbon dioxide comes out

Petra: ((reads aloud the text from the questionnaire)) it says explain in your own words what you consid- what you see happening in the different animations

Gloria: all right then it's what you see sort of ((make notes)) (9 s)

Petra: I wrote used up slash transforms

Here two conflicting perspectives become apparent. This is about how to explain the breathing process both described in the caption and visualised in the animation. The two girls at first conclude that there is a transformation in the lungs but then Gloria points out that it actually is a more complex process involving the gas exchange occurring inside the cells. Petra on the other hand refers to the written task where they explicitly have to explain what they 'see happening', in the animation. Gloria admits that it is what they can observe that they have to report in their notes.

These conflicting perspectives, between the task (as referred to by the students) and the visualisations, are also visible in the excerpt below, from the triad group. Here Martina, sounding somewhat annoyed over her companions reading of the text, stresses that they have to write down what they 'see'. Later on in this group's discussion, the same tension arises over what their assignment really is about.

Henric: are we going to explain what photosynthesis is?

Martina: we have to write down what we see

Veronica: photosynthesis

Henric: yea wait there it says ((reads the text about the photosynthesis on the screen)) the plants absorb

Martina: in your own words or

Henric: what do we have to write down (.) what's happening?

Martina: yea that's it

Henric shows that he is in a quandary over what their assignment is about. Martina emphasizes three times the explicit wording in the questionnaire, specifically what their task is about. When Henric is trying to read the text, accompanying the animation, Martina interrupts him, and stresses that it should be 'in your own words'. For Martina, reading the text obviously implies that they will not be able to describe what they see with their own words. Thus, she clearly regards the use of what is mentioned in the captions to be in conflict with their task.

DISCUSSION

The analysis shows how students watching the animations use expressions from their everyday life to talk about what is displayed on the screen. As they, in their capacity of being students, lack knowledge of the subject matter, they have to impose an interpretation of their own, and, they do this by drawing on a variety of resources. In their efforts to make the events in the animation meaningful, the students incorporate everyday language in their descriptions of the depicted processes. At times, this leads them to make unintended interpretations of the scientific model. However, such use of everyday language and even bodily experiences when attempting to grasp abstract phenomena, is not solely done by students, but also by professional scientists in their ordinary work (Ochs, Gonzales, & Jacoby, 1996). Consequently, we regard this as a pedagogical problem of a more general nature, and not specifically tied to the use of animations.

The earlier documented problem, that students tend to focus on perceptually salient features of the animation, could also be observed in our material. In relation to these features, Lowe (2003) found a predisposition by novices to impose simple everyday cause-effect relations on the interpretations of the animations. Examples of this kind, in the excerpts above, are the interpretations of molecules as ‘blowing’ into and away from the tree and oxygen being ‘consumed’. The analyses also show how easily such inferred notions are accepted and taken up by the co-participants, and, more problematically, in our case, even by the teacher. So, what kind of guidance would be necessary to overcome this problem then? An instructional text accompanying the animation could be one way of redeeming these issues, but this method offers no guarantee that the text will actually be attended to. Another suggested way of supporting animations has been narration coordinated with the animation (Mayer, 1997). Although Mayer et al. (2005) found no support for the superiority of computer based narrated animations over paper based annotated illustrations, they conclude that their study “should not be taken to controvert the value of animation as an instructional aid to learning. Instead, this research suggests that when computer-based animations are used in instruction, learners may need some assistance in how to process these animations” (p. 246). Obviously, teacher supervision could also provide students with the guidance needed for construing animations in an adequate way. This, however, being the panacea to all educational dilemmas, adds nothing new to our further understanding of the use of animations for specific learning purposes.

Another theme, worthy of further scrutiny and briefly touched upon in the analysis, is the topically isolated reasoning that can be observed in connection to the animations' superficial depiction of the biochemical processes. In biological terms, respiration takes place inside the cells and the gases are transported to and from the lungs with the blood. In the animation of breathing however, the gaseous exchange was only illustrated within the lungs; showing oxygen being inhaled and carbon dioxide leaving the lungs. This delimitation of the illustration in some cases leads to erroneous inferences, like carbon dioxide being formed in the lungs or originating from an outside airborne source. In the students' effort to answer the question about the origin of carbon atoms in the exhalation air, they had to turn to resources external to the actual animation. To make the judgement of when to go outside the provided material, and when to stick with it, is not a trivial task however. By using the written information in the caption most students were able to get the correct information. But without this source, they were restricted to either their previous knowledge, or to observing the animations. Given this latter scenario, a conclusion such as 'carbon dioxide reaching the lungs from an external source' is fully understandable.

In addition, we would like to comment on the distinctive situation of solving educational problems. As a general observation, students are often oriented towards the short-term goal of fulfilling a given task by the production of an answer to a specific question. When solving such a task, the students can use varying resources like earlier experiences, texts, instructional graphics and so on. Here, the conflict over *what* kind of resources they are expected to use, and *how* to use them, can be discerned in the students' argumentation. It is in this process that an explicit formulation of how to perform a given task can be interpreted as excluding other forms of resources. The formulation in the current assignment – "explain in your own words what you can see happening in the different animations" – did in this case lead some students to the conclusion that they, in their written answer, had to disregard their previous knowledge or what they could read in the text captioning the animations. Even though the intention with the question was to make the students draw their own conclusions from the animation and not only copy the text, this formulation in fact created an increased uncertainty of how to proceed. Considering this, it seems very important to pay great attention to the formulation of the assignments that students are going to perform in their work with animations.

FINAL REMARKS

Any graphical illustration of the complex biochemical processes involved in the carbon cycle will always entail simplifications of the real courses of events. As suggested by the observations above, perhaps animations, more so than static images, could help create the illusion that a complete process is being illustrated. Regardless of how sophisticated the animation becomes, there will always be grounds for misinterpretations. Prescribed ways of overcoming these drawbacks have been through increased interactivity (Tversky et al., 2002) or activities that generate explanations or answering questions during learning (Mayer et al., 2005). Other ways could be through instructional guidance, either written or narrative. When text and animation are simultaneously presented, the observers' visual attention has to be split between the animation and the text. In our study, the image *presenting* the animation was captioned, but as the sequence was started, the text disappeared. Hence, the students had to change between two pages when they wanted access to the written information versus the animations, something that should be reconsidered given a future re-design. Still, an important issue for the observed students was which of these two media, the animation or the text, were of superior significance when fulfilling their task. Here the formulations of their task sometimes led to the exclusion of the written information, and, even of their previous understanding of the subject matter at hand. To make the students integrate visual and verbal information, the task has to be formulated in a way that supports the utilisation of all available resources.

Finally, in no way do we regard the observations of our study as conclusive, they merely point out a field of investigation that needs further attention. In our current view, animations provide an interesting educational offering, with some pedagogical potential. They do not however, come without costs. What is suggested by our observations is that in a worst case scenario, the animation will operate as a counteracting force that – instead of supporting knowledge building and working against faulty interpretations – will do the exact opposite and take the role of an antagonist of conceptual development.

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REFERENCES

Barak, J., Sheva, B., & Gorodetsky, M. (1999). As `process' as it can get: students' understanding of biological processes. *International Journal of Science Education, 21*(12), 1281-1292.

Brown, C. R. (1990). Some Misconceptions in Meiosis Shown by Students Responding to an Advanced Level Practical Examination Question in Biology. *Journal of Biological Education, 24*(3), 182-186.

Brown, D. E. (1992). Using Examples and Analogies to Remediate Misconceptions in Physics: Factors Influencing Conceptual Change. *Journal Articles; Reports - Research, 29*(1), 17-34.

Camp, J. J., Cameron, B. M., D., B., & Robb, R. A. (1998). Virtual reality in medicine and biology. *Future Generation Computer Systems, 14*, 91-108.

Cañal, P. (1999). Photosynthesis and 'inverse respiration' in plants: an inevitable misconception? *International Journal of Science Education, 21*(4), 363-371.

Eisen, B., & Stavy, R. (1993). How to make learning of photosynthesis more relevant. *International Journal of Science Education, 15*(2), 117-125.

Euler, M., & Müller, A. (1999). *Physics learning and the computer: A review, with a taste of meta-analysis.* Paper presented at the Second International Conference of the European Science Education Research Association.

Flick, L., & Bell, R. (2000). Preparing tomorrow´s science teachers to use technology: Guidelines for science educators. *Contemporary Issues in Technology and Teacher Education, 1*, 39-60.

Goh, N.-K. (1993). Some Misconceptions in Chemistry: A Cross-Cultural Comparison, and Implications for Teaching. *Australian Science Teachers Journal, 39*(3), 65-68.

Goodwin, C. (1994). Professional Vision. *American Anthropologist, 96*(3), 606-633.

Ivarsson, J. (2003). Kids in Zen: computer-supported learning environments and illusory intersubjectivity. *Education, Communication & Information, 3*(3), 383-402.

Ivarsson, J. (2004). *Renderings & reasoning: studying artifacts in human knowing*. Göteborg: Acta Universitatis Gothoburgensis.

Jones, D. G. C. (1991). Teaching Modern Physics--Misconceptions of the Photon That Can Damage Understanding. *Physics Education, 26*(2), 93-98.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Science, 4*(1), 39-103.

Kameas, A., Mikropoulos, T. A., Katsikis, A., Emvalotis, A., & Pintelas, P. (2000). EIKON: Teaching a high-school technology course with the aid of virtual reality. *Education and Information Technologies, 5*, 305-315.

Karr, T. L., & Brady, R. (2000). Virtual biology in CAVE. *Trends in Genetics, 16*, 231-232.

Lindwall, O., & Ivarsson, J. (2004). What makes the subject matter matter? Contrasting probeware with Graphs & Tracks. In J. Ivarsson (Ed.), *Renderings & Reasoning. Studying artifacts in human knowing* (pp. 115-143). Göteborg: Acta Universitatis Gothoburgensis.

Lindwall, O., & Ivarsson, J. (in press). Differences that make a difference: contrasting the local enactment of two technologies in a kinematics lab. In S. Ludvigsen, A. Lund, I. Rasmussen & R. Säljö (Eds.), *Learning across sites; new tools, infrastructures and practices*. Amsterdam: Elsevier.

Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. *European Journal of Psychology of Education, 14*, 225-244.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction, 13*, 157-176.

Mayer, R. E. (1997). Multimedia learning: are we asking the right questions? *Educational Psychologist, 32*, 1-19.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge: Cambridge University Press.

Mayer, R. E., Hegarty, M., Mayer, S., & Campbell, J. (2005). When Static Media Promote Active Learning: Annotated Illustrations Versus Narrated Animations in Multimedia Instruction. *Journal of Experimental Psychology: Applied, 11*(4), 256-265.

Mikropouls, T. A., Katsikis, A., Nikolou, E., & Tsakalis, P. (2003). Virtual envi-ronments in biology teaching. *Journal of Biological Education,, 37*, 176-181.

Mork, S. (2005). *ICT in Science Education: Exploring the Digital Learning Materials at viten.no.* University of Oslo.

Nicoll, G. (2001). A Report of Undergraduates' Bonding Misconceptions. *International Journal of Science Education, 23*(7), 707-730.

Ochs, E., Gonzales, P., & Jacoby, S. (1996). When I come down I'm in the domain state: grammar and graphic representation in the interpretive activity of physics. In E. Ochs & E. A. Schegloff (Eds.), *Grammar and interaction* (pp. 328-369). Cambridge, MA, England: Cambridge University Press.

Odom, A. L. (1995). Secondary & College Biology Students' Misconceptions About Diffusion & Osmosis. *American Biology Teacher, 57*(7), 409-415.

Petraglia, J. (1998a). *Reality by design: The rethoric and technology of authenticity in education*. Manwah, NJ: Lawrence Erlbaum.

Petraglia, J. (1998b). The real world on a short leash: the (mis)application of constructivism to the design of educational technology. *Educational Technology Research and Development, 46*(3), 53-65.

Rebetez, C., Sangin, M., Bétrancourt, M., & Dillenbourg, P. (2005). Learning from animations is

enabled by collaboration. *Manuscript in preparation*.

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. *Journal of Research in Science Teaching, 30*(8), 919-934.

Sanger, M. J., & Greenbowe, T. J. (1999). An Analysis of College Chemistry Textbooks as Sources of Misconceptions and Errors in Electrochemistry. *Journal of Chemical Education, 76*(6), 853-860.

Schnotz, W., Böckheler, J., & Grzondziel, H. (1999). Individual and co-operativ learning with interactive animated pictures. *European Journal of Psychology of Education, 14*, 245-265.

Schnotz, W., & Rasch, T. (2005). Enabling, facilitating, and inhibiting effects of animation in multimedia learning: Why reduction of cognitive load can have negative results on learning *Educational Technology Research and Development., 53*(3), 47-58.

Seymour, J., & Longden, B. (1991). Respiration-that´s breathing isn't it? *Journal of Biological Education, 25*(3), 177-183.

Songer, C., & Mintzes, J. (1994). Understanding cellular respiration: an analysis of conceptual change in collage biology. . *Journal of Research in Science Teaching, 31*, 621-637.

Stahl, G. (2006). *Group cognition: computer support for collaborative knowledge building*. Cambridge: MIT press.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies, 57*, 247-262.

Key terms

Computer animation: The art of creating moving images via the use of computers

Conceptualisation: Creating an idea or explanation and formulating it mentally

CSCL: Research area in supporting collaborative learning with assistance of computer artefacts

Interactive: Refers to computer software which responds to input from humans

Misconception: A false conception or abstract idea that is held by a person

Simulation: An imitation of some real process

Visualisation: Technique for creating images or animations to communicate a message

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Study II

Animation and grammar in science education

Learners’ construal of animated educational software

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ABSTRACT

This case study reports on how students, working collaboratively, interpret and construct a written report of the events described in animated educational software. The analysis is based on video recordings of two upper secondary school students while they are endeavouring to construe an animated sequence of the mouldering process. How the students grammatically construct their written account by means of available semiotic resources (i.e., animation and educational text) provided by the software is investigated. The results show that attentionally detected features of the animation take the role of active subjects in the students' description of the animated phenomena. When framing their sentences, the students derive noun phrases from animated active subjects and from the educational text. In the students' efforts to express themselves in their own words they use verbs that differ from the educational text. These two actions together contribute to giving the students' description of the process a character of a non-scientific explanation. Lacking relevant subject matter knowledge, the students cannot judge whether they have given an adequate account or not. The only way the students have to appraise their written report is to check if it is grammatically correct. It is concluded that it is essential to consider both cultural and semiotic processes when designing technology-supported educational approaches to the teaching of scientific concepts.

INTRODUCTION

Biochemical processes occur at a micro level that is impossible to observe ocularly. This fact poses a considerable problem for educators when having to demonstrate such invisible events to be conceptualised by students. To explain and make these unobservable phenomena understandable, scientists and science educators strive to depict these microscopic phenomena in ways that make them visible. Such models are mere representations of scientific concepts and it is of vital importance for science educators to gain an insight into how learners understand the phenomenon illustrated. Mostly, the only account of students' conceptualisation is a verbal or written statement. Often, students do not present an explanation that is in line with the intended learning outcome and hence not in accordance with canonical science. Such unintended interpretations made by the students are referred to as misconceptions (e.g., Cañal, 1999; Kuech, Zogg, Zeeman, & Johnson, 2003; Morton, Doran, & MacLaren, 2008) or erroneous ideas (e.g., Sanders, 1993). Most often educators do not know how, or why, some ideas arise that are not in accordance with scientific knowledge. One way of unravelling students' comprehension of scientific concepts which are introduced is by making a close inspection of their reasoning about observed phenomena.

Aim of study

The analysed material comes from a study that aims to investigate how secondary school students make use of and construe computer animated biochemical processes in the carbon cycle. In this article a case study is reported that aims to examine how two students manage to complete a written report of a biochemical process that is depicted in computer animated software. The analysis includes how the students grammatically construct their written account of what is happening in the animated processes by means of their available semiotic resources. By analysing the reasoning and interaction taking place when groups of students collaborate in studying a set of animations, the study aspires to gain insight into students' interpretations of the depicted processes. The close relationship between language and thinking (Vygotsky, 1934/1986) and the socio constructivistic perspective form the basis of the study and analysis. This epistemological standpoint is discussed in a socio cultural approach where discourse and knowledge are mediated by tools and constituted in a social practice (Säljö, 1998; Wertsch, 1991).

Earlier research

To understand the circulation of matter in the carbon cycle, it is important to realize that air contains matter in the form of gases such as oxygen and carbon dioxide. Research, though, has shown that students do not imagine air as matter (e.g., Smith, Maclin, Grosslight, & Davis, 1997). "Because students think that matter is something that they can see, touch and feel, they have problems conceiving of gases as matter" (ibid., p. 799). From an educational point of view, one way of making it possible for students to envisage gases as matter may be by visualising events of gas molecules involved in the gas exchange between organic materials.

Students are more likely than professionals to think of models as physical copies of reality rather than as constructed representations that may embody different theoretical perspectives (Grosslight, Unger, Jay, & Smith, 1991). Nevertheless, a model assumes a connection between the depicted phenomena and reality that requires the observer to make an association to the real world. As Chittleborough, Treagust, Mamiala and Mocerino (2005) point out: "the use of any model requires the learner to identify the analogue (the model) with the target (reality)" because "without the learner making this connection, the model has no value" (p. 196). When examining how professional chemists and chemistry students (i.e., novices) responded to a variety of chemistry representations, including animations, Kozma and Russell (1997) found that the surface feature of the display was attended to by both experts and novices. The difference though, was that while the chemists focused on underlying concepts and principles, the students seemed to be constrained by the media and their surface features.

In a study of how students extracted information from animated weather maps, Lowe (1999) revealed that the processing of animations is driven by dynamic effects and that "much of the information extracted was perceptually salient rather than thematically relevant" (p. 225). Lowe (2003) also found that compared with static graphics, the inclusion of temporal change in a visual display introduces additional processing demands. This implies that experts for example, designers of illustrations for science education and teachers might not see the same thing in the graphics as a novice. As Krange and Ludvigsen (2008) remark in their study of a computer-based 3D model for teaching molecular concepts to secondary school students:

> In complex knowledge domains, like the one studied here, the meaning potentials carry a history that is often invisible to the students. This knowledge domain is constructed over extensive periods of time, and only a small part of it is inscribed in the tools. This means that the students only get access to the top of the iceberg of this knowledge base, and what part of this that they manage to realise in practice is an empirical question. (p. 29)

Consequently, a major concern for designers and educators must be to gain knowledge of the ways students construe and make meaning out of multimedia learning tools representing scientific phenomena.

Expressing events linguistically

Learning from experiencing a multimedia event also requires the learner to transform the observed phenomenon linguistically. Halliday (2004) contends that from early childhood, our experiences are transformed into meaning, and this transformation is affected by the grammar of our language, "grammar transforms experience into meaning" (p. 11). "Understanding and knowing are semiotic processes—processes of the development of meaning in the brain of every individual, and the powerhouse for such processes is the grammar (ibid., p.11)". Thus, according to Halliday, to understand something is to transform it linguistically into meaning and the result is what we refer to as knowledge. Bakhtin (1986), on the other hand, stressed the dialogical perspective on humans' meaning-making processes and contended that "the relation to meaning is always dialogic" and that "even understanding itself is dialogic" (p.121). Bearing in mind these views, I would instead argue that when we use grammar in a communicative process our experiences are structured in a certain ways.

Lemke (1990) argues that scientific language is a special genre and constitutes a particular way of talking about the world. Scientific language displays some specific features through "a preference in its grammar for using the passive voice" and a "grammatical preference for using abstract nouns derived from verbs instead of the verbs themselves" (ibid., p. 130). This way of describing occurrences, in the passive form and with the usage of nouns instead of verbs, is not what students are used to in other areas, which may result in students finding science hard to understand and that they may therefore refrain from science (Lemke, 1990). The specialised language of science thus has implications for how students view the subject (Lemke 1990; Halliday 2004).

When having to describe a scientific phenomenon linguistically, the students face the problem of describing the events in writing. "The sentence in its basic structure consists of a verb and one or more noun phrases, each associated with the verb in a particular case relationship" (Fillmore, 1968, p. 21). According to Fillmore, these 'noun phrases' are associated with the verb in a particular case relationship:

> The case notions comprise a set of universal, presumably innate, concepts which identify certain types of judgements human beings are capable of making about the events that are going on around them, judgements about such matters as who did it, whom it happened to, and what got changed. (p. 24)

Consequently, the problem of lexical selection of verbs and nouns for insertion in a sentence depends on particular arrays of such cases[1]. "In lexical entries for verbs, abbreviated statements, so-called 'frame features' will indicate the set of case frames into which the given verbs may be inserted". (ibid., p 27) In the frame feature for a verb like 'move', it is necessary to specify an object such as a 'stone'; the sentence will then be 'The stone moved'. There are also optional elements to be included in the frame feature for the verb 'move' as an 'animate subject' and an 'instrument phrase' as in the sentence: 'He moved the stone with a lever' where 'He' represents the 'animate subjects' and the 'lever' the 'instrument'.

Tomlin (1997) investigated how conceptual representations of visual events are mapped into language, and argues that we should start by looking at the 'attentional focus'. He proposes that when viewing a dynamic event "some

[1] For classification of cases that need to be included, see Fillmore (1968, p. 26-27).

component is ‘attentionally detected’ at any given moment in time and that this allocation of attention is pre-linguistic.” (ibid., p. 171). As regards the temporality in dynamic events and its consequences for language construction, Tomlin argues:

> Finally, it is essential to keep in mind that conceptual representations are dynamic in nature. Events are witnessed rapidly and in real time. It is conventional to think of propositional representations as somehow enduring or atemporal and that informational statuses associated with components of the propositions—topic status, focus status, referential status—also endure and are atemporal. But we will argue here that grammars look directly at event representations during language production, so the temporality of those representations most assuredly matters. (p. 171).

An utterance describing the events is then formulated lexically where the grammar identifies the attentionally detected parameter “and it maps just that parameter onto syntactic subject” (ibid., p. 172). In an experiment, where observers were presented with a set of animated sequences, Tomlin (1997) showed that “speakers do assign a focally attended referent to the syntactic subject in English as they formulate their sentence for production” (p. 179). Without cueing objects, “large size or animacy may simply result in a particular attentional detection, and it is this which is mapped onto subject” (ibid., p. 182).

METHODS

In the study reported here, the students were supposed to linguistically describe the events they could observe in the animated sequences on a computer screen. Animation for educational purposes is still in its infancy as a teaching aid and needs to be addressed in educational research. The question is then how to do research on complex media artefacts from which students make diverse meanings depending on their different backgrounds. Lemke (2006) proposes that: “We replace an input-output model with a "tracer" model. We open the black box of intermediations that lie between any input and any output and we follow or trace in detail the actual processes by which outcomes are arrived at.” (p. 9). Applying such a research strategy will, of course, not offer a general theory of how simulated or animated multimedia presentations will be construed by students in an educational setting. Instead, case studies of learning situations involving educational artefacts should provide insight into trajectories of students’ reasoning when endeavouring to make meaning of the observed representation (ibid.).

Understanding how representations are used and construed in a learning situation requires studies of multimodal recourses used by the learners such as talk, gestures and gazes, when interacting with the representative tool and each other. When we socially organise ways of seeing and understanding events, Goodwin (1994) demonstrates the practice of “highlighting” which work to make “specific phenomena in a complex perceptual field salient by marking them in some fashion”(p. 606).

The way students talk about the depicted processes can give us an insight into students’ conceptualisation of the knowledge domain since “the mastery of science is mainly a matter of learning how to talk about science” (Lemke, 1990, p. 153). Language, however, is not the only semiotic resource that is used in meaning-making processes between humans. Instead, a variety of multimodal resources such as intonation and all kinds of body language combine to form an integrated system for communication (e.g., Lemke, 1998, 2006).

To address this problem of representing the variety of semiotic resources used by the students when interacting with each other and the interface, i.e. the computer screen, I have chosen to demonstrate the analysed episodes by employing a mode borrowed from comics. This style – also referred to as sequential art (Eisner, 1985; McCloud, 1994) – of representing the analysed material allows us to show image shots from the video segments connected in strips to demonstrate the unfolding character of and sequentiality in the students’ interaction. I believe this style, as argued elsewhere (Ivarsson, in press), to be a productive mode for visually presenting the learners’ multimodal conduct when working with a representational tool. Like all modes for re-presenting audio-visual material in printed form, sequential art inevitably lacks some of the information on the original videotape. When presenting the episodes as strips of frames with speech bubbles, you lose information available in a traditional CA transcript such as intonation, pausing, overlapping speech, etc. With the purpose of supplying this information, a conventional transcript with the Swedish text and the English translation is appended.

Interaction analysis of knowledge building in small groups is an emerging and promising method in the area of computer supported collaborative learning (CSCL).

> Group learning has a qualitative advantage over individual learning. It is not just that two minds are quantitatively better than one or that the whole has a Gestalt that exceeds the sum of its parts. The synergy of collaboration arises from the tension of different perspectives and interpretations. During discourse, a meaning is constructed at the unit of the group as ut-

terances from different participant build on each other and achieve an evolving meaning. (Stahl, 2006, p. 299)

Wegerif (2007) contends that students learn to think better in groups by learning to listen to each other and to question their own initial ideas. Thus, Wegerif proposes a dialogic framework for teaching, using CSCL where reflective dialogues are seen as an end in itself. Teasley and Roschelle (1998) argue that the essential advantage of collaborative problem solving is that it enables the construction of a shared conceptual structure, which they call a Joint Problem Space that "supports problem solving activity by integrating semantic interpretations of goals, features, operators and methods" (p. 2). They contend that the use of the computer screen as a shared focus for learning that occurs socially contributes an important resource that mediates collaboration. Studying dyads of students using a dynamic computer simulation of a model of velocity and acceleration, they conclude that "in ordinary circumstances, one cannot imagine two 15 year olds sitting down for 45 minutes to construct a rich shared understanding" (p. 26). Concerning the learners' capacity to jointly create meaning of a simulated phenomenon, the authors contend that their study "demonstrates that students have powerful resources for constructing shared knowledge" (p.28).

Adhering to my research interest in how students collaboratively construe meaning in a computer supported environment, I will apply a 'dialogic' research approach (Arnseth & Ludvigsen, 2006), where the analytical concern is primarily the problem of how the computer application provides a framework for students' interaction. By viewing understanding and cognition as socially constructed and distributed among the participants in an ongoing activity, I attempt to give details of the events in a multimodal communication that result in the participants' shared explanation. When analysing human-computer interaction (HCI), Greiffenhagen and Watson (2007) found that the focus is not just on the interlocutors' problems in understanding each other, it is more on what they are supposed to achieve in the activity. In the study reported in this article, the students endeavour to construct a cooperative description of what the computerised animations are illustrating. Studying how learners come to agree on a text describing the observed computer simulated model enables us to gain an insight into the meaning-making processes taking place in the student-student interaction and in the student-interface relations.

RESEARCH DESIGN

This study constitutes the second part of a design experiment (Brown, 1992) where topics of the educational sequences in the carbon cycle are studied in learning settings. In the first study (Karlsson & Ivarsson, 2008), a computer-animated program was designed and tested in a science course. The educational application[2] includes animations visualising gas exchanges in biochemical processes in the carbon cycle. In the four processes: photosynthesis, breathing, combustion and mouldering, animated sequences depict gas molecules either being absorbed or emitted. The index page shows an educational text, describing the main outlines of the carbon cycle and a menu where one can choose between pages describing each process. The web pages for each process are furnished with an explanatory text and a link to an animated sequence of the events. The application is interactive in the sense that the user can choose in which order to view the processes and play the animated sequences. This enables the students to replay and freely explore the animations and captioned web pages.

In the initial study, there was no special tutorial introduction of the topic before the students started their exploration of the animations. The students were just given brief instructions about how to manage and navigate in the learning environment. The analysis of the first study revealed that the students faced problems in interpreting and drawing conclusions from the animated sequences. Observed problems were the risk of students focusing their attention on misleading aspects of the animation and the occurrence of isolated reasoning within each of the processes. As a way of addressing some of these problems, a new lesson plan was drawn up containing an elaborated introduction of the knowledge area. In the subsequent study—accounted for in this article—the same application was used but the introduction to the subject field was more exhaustive. Before the students started working with the application, they attended a one-hour lesson dealing with the processes in the carbon cycle. The aim of the introductory lesson was to provide the students with more knowledge of the subject in order to facilitate their construal of what was happening in the processes depicted. Another problem revealed in the initial study was the students' varying understanding of what resources they were expected to use when performing a given task. The students' assignment was formulated as: *"Explain in your own words what you can see happening in the different animations".* This formulation proved to be troublesome for some of the groups as there were conflicting ideas among the members about what they were supposed to describe in their written answer. Was it just to describe what they actually could see happening in the animated sequences and thereby disregard their previous knowledge and what they could read in the text captioning the an-

[2] Available at: http://www.init.ituniv.se/~gorkar

imations? Or was it to give an account of what they really knew about what happened in the processes? Even though the question was intended to make the students draw their own conclusions from the animation and not just copy the text, the formulation in fact created increased uncertainty about how to accomplish their task. In view of this, it seemed important in this second study to pay attention to the formulation of the assignments that the students were going to perform. Accordingly, in this subsequent study, the students' assignment was simply expressed as: "*Explain what is happening in the different processes that the animations are describing*". This was to avoid the conflict situation and allow the students to utilise all available resources when describing what is happening in the animated processes.

The study was conducted in a Swedish upper secondary school where students in four classes, attending a course in natural sciences in school, participated. The course, dealing with basic scientific issues, was attended by 12 boys and 53 girls aged 16-18 years. Three of the four classes consisted of students enrolled in aesthetic student programs, which accounts for the large proportion of girls. The fourth group of students was enrolled in a science program and consisted of nine boys and ten girls. Prior to the work with the animations, all classes had a lesson with their teacher dealing with the processes in the carbon cycle. The students were instructed to work in dyads or in a few cases in triads with the task of interpreting what was happening in the animated sequences.

Just before starting their exploration of the animations, the participants were given a brief introduction for about ten minutes, instructing them about where to find the website and how to work with the learning application. The groups were then provided with an assignment sheet requesting them to explain what was happening in the four processes depicted in the animated sequences: photosynthesis, breathing, combustion and mouldering. It was presented as a joint assignment where they had to discuss, reflect and compare their different views within the groups. The time allotted for completing the assignment was 30 minutes but most groups used about only 20 minutes for their discussion and completion of the assignment sheet.

Video recordings were made of seven randomly selected groups, five from aesthetic programs and two from the science program. The seven groups were videotaped during the entire session while they were carrying out their assignment of construing the animations. The video recordings were analysed to gain an understanding of how the students interpreted their tasks and made meaning out of what they observed in the animation. In accordance with Jordan and Henderson's (1995) prescription for interaction analysis, I started by identifying what was analytically interesting in the video-recorded material. The whole data corpus was then checked to see whether the generalizations were valid. The segments selected were then viewed and discussed in an interdisciplinary work group of researchers. All text in the software as well as the communication was in Swedish and has been translated into English by the author.

RESULTS

A general feature throughout the seven video-recorded groups analysed was the students' efforts to create written accounts about what was happening in the animated sequences. The students engaged in creating a joint description and explaining in colloquial terms what was shown in the animations. As an example of how the animations were interpreted and formulated in text, the reasoning of two female students, attending an aesthetic program, is discussed in the following analysis. The girls were video-recorded during their entire session working with the learning application but the analysis will focus on the part where they endeavour to explain what is happening in the mouldering process.

The educational text

At the top of the web page, describing the mouldering process, there is an educational text that says:

> Dead plants and animals are attacked by microorganisms. These decomposers utilise the energy in the carbon compounds for their own energy consumption. With the release of energy, the decomposers use oxygen in the air that combines with the carbon in the carbon compounds and forms carbon dioxide. When mouldering, oxygen is consumed and carbon dioxide is produced.

Underneath the text, there is an image of a decaying log on the ground, linking to the animation of the mouldering process. In the animated sequence, oxygen molecules are seen approaching the decaying log from the side and when reaching the log, carbon dioxide molecules are seen leaving the log. After a while, the log darkens and collapses. The students switched between the window showing the animation and the introduction page where they could read the explanatory text.

The students' written report

In the questionnaire where the students were asked to explain what was happening in the mouldering process, the two girls wrote:

“Oxygen surrounds the tree and is attacked by microorganisms. Carbon compounds are mixed in and form carbon dioxide that is let out. Mouldering produces carbon dioxide”.

This answer does not meet the standards of current canonical science. Consequently, their teacher did not approve of their written account and commented:

“They demonstrate a great lack of knowledge; they only have some understanding of mouldering”.

The teacher was also quite bemused by the students’ formulations and in addition remarked:

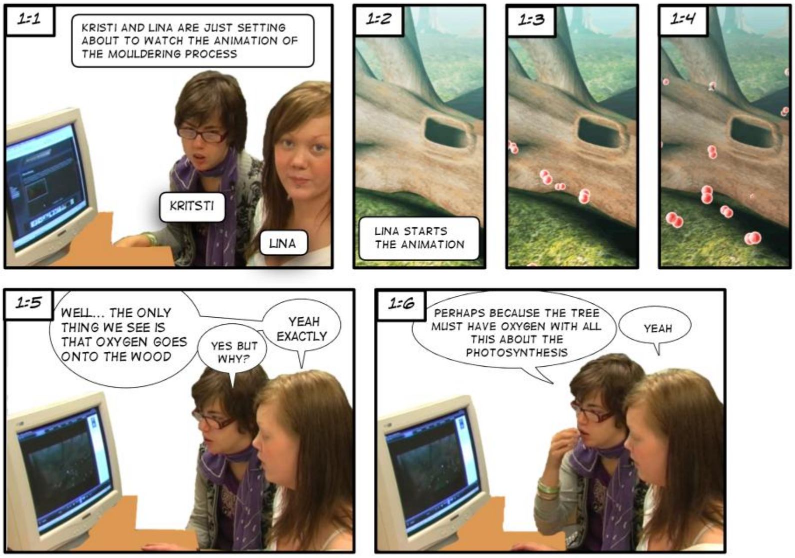
“Do they really mean that oxygen is attacked by microorganisms? Where are the carbon atoms mixed, in a pot or what? I am very uncertain whether they have understood that it is the micro-organisms that do the job”.

From only reading the girls’ account, one could conclude that they have not paid enough attention to the question or put enough effort into trying to work out a satisfying explanation and that they have therefore given an inadequate answer. By means of a close inspection of the video-recorded material, I want to re-trace the events that eventually led to the students’ written account. The analysis aspires to uncover how the students’ conclusions were produced and negotiated as a consequence of their interactional work. Important questions that will be pursued are what their line of reasoning was and how they constructed their written report. The data proved to appear in discernible sections and are presented in four parts where the two students at first try to: find out a causality in the animated sequence (episode 1-2), then construe the meaning of the educational text (episode 3), formulate their own report of what is happening in the mouldering process (episode 4-6), and finally assess their written account (episode 7).

Finding out what is happening

In the opening episode, the girls have already gone through the first three processes in the carbon cycle and begin watching the animation of the mouldering process. In the sequence they can witness the oxygen molecules moving towards the log on the ground.

Episode 1



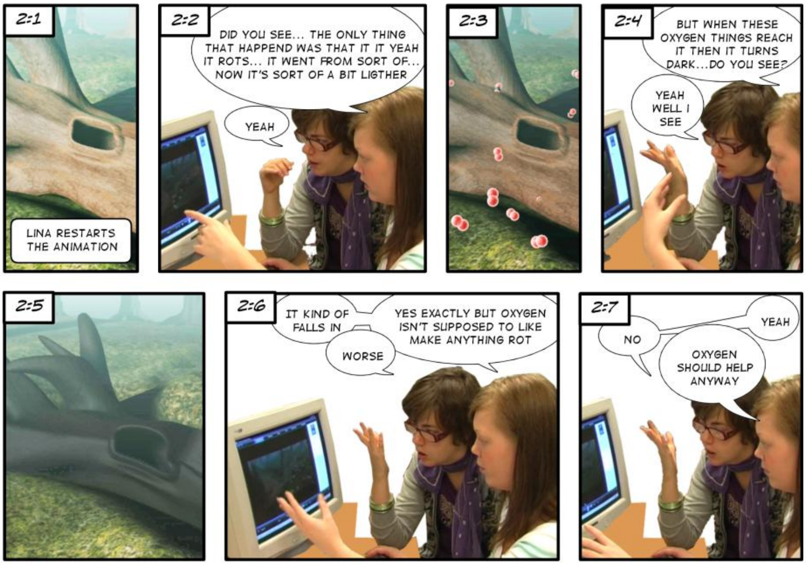
This episode, from the girls' initial encounter with the animated sequence of the mouldering process, reveals several confusing parts for them to deal with in their interpretation of what is happening. After observing the animation, Lina remarks (panel 1:5) that "the only thing we see is that oxygen goes onto the wood". With this remark, Lina has assigned the oxygen molecules an 'active' role, thus making them an agent in the event. As a consequence of being 'attentionally detected', the oxygen molecules are "assigned to subject" (Tomlin, p. 178).

Kristi's utterance in the last frame that "the tree must have oxygen with all this about the photosynthesis", appears to be troublesome for some reason. They are now examining the mouldering process and not photosynthesis, which is visualised in a separate sequence and which they have already described. Another problematic fact is that in photosynthesis, it is carbon dioxide that is assimilated and oxygen that is emitted. Furthermore, "the tree" referred to is the decaying log on the ground and since only the green parts of a living plant photosynthesise, a decaying log cannot be part of the process. However, what seems most important to Kristi is finding an explanation of the movement of oxygen molecules towards the log.

During the girls' work with the animation, it is noticeable how they try to find cause, effect and sequentiality in their discussion about what is happening in the animated process. The first thing they observed in the animation of the mouldering process was the oxygen molecules moving towards the log. These molecules from now on constitute a core agent in their effort to give a description of what is happening in the animation.

After some computer problems, Lina restarts the animation. The turns concerning the reloading problem have been omitted and in the next episode, we continue to follow the girls’ discussion about what is happening when the oxygen molecules reach the log.

Episode 2



When they watch the animation a second time Lina notes (2:2) that initially the log is light brown. She points at the screen where the log is visible in order to get her partners attention to what she is talking about. Lina also remarks (2:4) that it is when the oxygen molecules “reach” the log that it turns dark and collapses. This remark implies that a temporality is imposed on the process, which means that it is not until the oxygen molecules reach the log that it starts decaying. Kristi agrees with Lina’s observations but at the same time produces a gesture of puzzlement (2:4) to accompany her talk. In panel (2:6) Kristi utters the word “worse” to describe what happens to the log when it darkens and collapses. While Lina mirrors Kristi’s gesture she articulates the problematic aspect of the observation by uttering, “oxygen isn’t supposed to like make anything rot”. With this utterance, a conflict is established concerning what seems to be happening in the animation and what she thinks will happen. Lina continues with, “oxygen should help anyway” (2:7) and Kristi agrees.

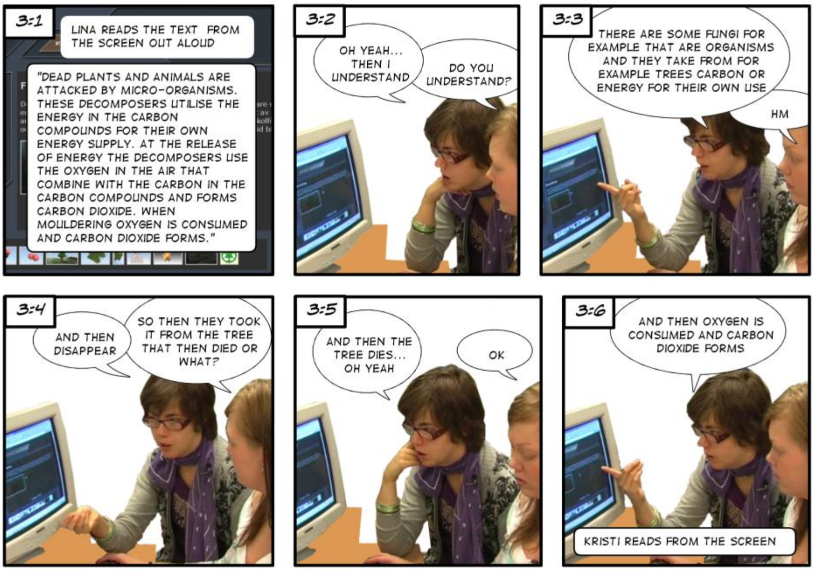
Lina construes her observation of the animated sequence as oxygen being the agent, seemingly causing the log to rot. This conclusion puzzles her and in some way contradicts her concept of oxygen as something that “shouldn’t kind of make anything rot” and should instead “help”. The students’ interpretation of oxygen causing decay contradicts their preconception of oxygen as being required for the vital process of breathing and hence something ‘life giving’.

It is noteworthy that they do not comment on the carbon dioxide and do not seem to notice these molecules leaving the log. The students’ attention seems to be focused on the oxygen molecules and their effect on the log. In the animation, oxygen molecules first appear to move towards the log and only after a while are the carbon dioxide molecules seen emerging from the log. In the girls’ interpretation of the animation, oxygen molecules are, as the first “attentionally detected” objects, attributed the active agent, directing their description of what is happening in the animation.

Construing the educational text

Apparently, in an attempt to find an explanation of their bewildering finding that oxygen causes the log to rot, Lina minimises the window displaying the animation to be able to read the text describing the mouldering process. The girls look at the text and Lina reads it out loud while Kristi reads it silently.

Episode 3



When the girls have finished reading the text, Kristi in panel 3:2, exclaims, “then I understand”. What she understands or means by understanding is not obvious. As a response, Lina asks in an astonished tone “do you understand”. Lina’s question is sequentially and anaphorically linked to Kristi’s utterance about understanding.

Kristi, in the next panel (3:3), replies to Lina’s question by making an effort to explicate the text by expressing it in her own words: “that there sort of are some fungi for example that are organisms and they take from, for example, trees, carbon or energy for their own use”. This is a rephrasing of the first two sentences in the educational text that says: “Dead plants and animals are attacked by micro-organisms. These decomposers utilise the energy in the carbon compounds for their own energy consumption.” With her explanation, Kristi shows that she regards Lina’s question “do you understand” as an indication that she for her part did not understand and as a request for a clarification of the meaning of the text. The girls’ “formulations of understanding or lack of understanding are used to discern and articulate problems” (Lindwall, 2008, p. 248).

Kristi displays her ‘understanding’ by reformulating the educational text in her own words and by mentioning “fungi” as an example of what a decomposer might be. The text only refers to microorganisms as decomposers but does not specify what kind of organisms they might be. In her explanation, Kristi shows that she obviously has some pre-knowledge of fungi being decomposing microorganisms. By using the expression “they take”, she gives an everyday description of what is expressed in the text as “utilise”. In her view, the concept of ‘utilise’ seems to be equivalent to something being ‘taken’. The term ‘utilise’ used in the text implicates an agency in the process that Kristi transforms into the even more active term ‘take’. Kristi’s purpose of this transformation of the rather scientific word ‘utilise’ could be to make it easier for her partner to grasp the meaning but it might also be a function of the students’ ambition to express themselves in ‘their own words’, as will be discussed later. Kristi also clarifies by using the example of “trees” instead of the texts’ somewhat imprecise wording “Dead plants and animals”. The animation depicting a log lying on the ground may facilitate the connection to “trees” rather than other dead organisms as mentioned in the educational text. Kristi then says that fungi take “carbon or energy” from “trees”, thereby separating carbon and energy into two entities, although the text says that: “decomposers utilise the energy in the carbon compounds”. It has not been clarified for her by the text that energy is chemically bound in the carbon compounds and she describes energy and carbon as two separate entities. Kristi’s claim that she understands can therefore not be said to be completely in accordance with the scientific text.

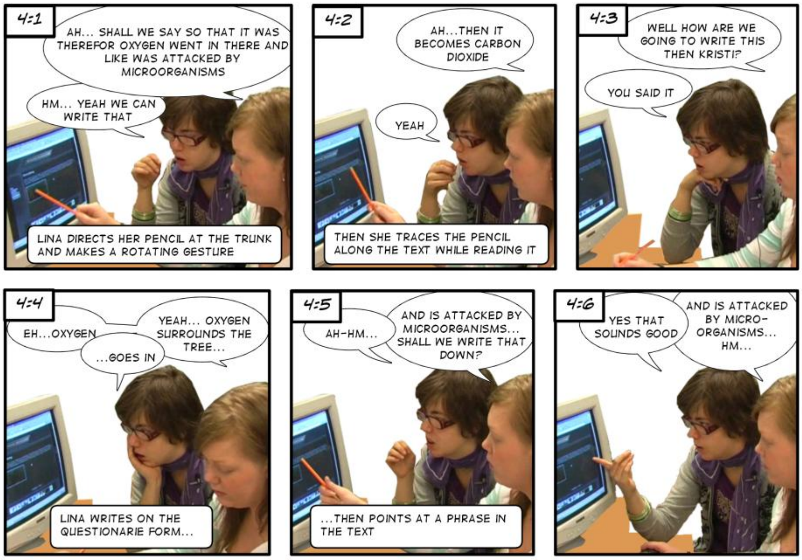
After listening to her companion’s explanation in panel 3:3, Lina utters a “hm”. Kristi’s reply, “and then disappear” (3:4), indicates that she perceives Lina’s “hm” as indicating that she has not quite grasped the meaning of her explanation and needs more clarification. Kristi’s utterance “and then disappear” is a paraphrasing of what the text describes as “the release of energy”. The expression “the release of energy” is rather vague—meaning the transformation from one form of energy into another—and Kristi replaces ‘release’ with the word ‘disappear’. Again, we can see Kristi transforming a word from the educational text into her own expression. In response to this, Lina says “so then they took it from the tree that died then or what”. What she is referring to with “they took it” is not obvious but can be seen as an attempt to make a causal connection between something that takes something from the tree, and what caused the death of the tree. The educational text does not mention anything about what caused the death of the tree and Lina’s utterance suggests that she is trying to find a reason for the death of the tree. Kristi’s reply, “and then the tree dies oh yea” (3:5), confirms Lina’s suggestion and can be seen as a reaction to the ending of the utterance with an “or”, requiring a response. Lina verifies that she follows her partners reasoning by saying: “OK”. Kristi, in the last panel (3:6), then points at the final sentence in the text and reads out aloud, “then oxygen is consumed and carbon dioxide is formed", thus bringing to an end their exploration of the educational text.

In this episode, the girls have discussed what the text means and they seem to have grasped the intended meaning, namely that microorganisms consume carbon compounds for their energy supply; in this process, consuming oxygen and forming carbon dioxide.

Formulating their own account

The assignment directs the students to write down an account of what they can see happening in the animated sequence. In the following episodes, we will follow how they strive to formulate this written account of the events in the mouldering process.

Episode 4



With the utterance "shall we say so", in the first panel, Lina tacitly ratifies the explanation collaboratively constructed in the previous episode. Her proposal also transitions the activity into composing their report. Then she points at the trunk on the still image with a rotating gesture and utters "it was therefore oxygen went in there", apparently referring to the animated oxygen molecules reaching the log. Then she turns back to the text and finds the phrase "attacked by microorganisms" which she utters as a suggestion to be added to the observation of the oxygen molecules reaching the log. Kristi confirms this by saying "yeah we can write that". Thus, according to this description, the oxygen molecules go into the log and are there attacked by microorganisms. The girls attempt to combine what they have observed in the animation with the wordings in the text has radically changed the content of the educational text.

Oxygen molecules are perceptually salient in the animated sequence—neither microorganisms nor carbon hydrates can be observed in the animation—and becomes prominent when Lina constructs a story about what is happening in the process. She then takes the phrase, "attacked by microorganisms" from the text where it is used to describe the microorganisms' consumption of energy-rich carbon hydrates from the tree. Using this phrase as a subordinate clause to the observation that oxygen goes onto the log produces the meaning that it is the oxygen molecules that are being attacked by microorganisms instead of carbon hydrates as described in the educational text. The verb 'attacked' is not an invention by the student as it appears in the educational text; however, when re-used together with the observation from the animation, it creates a new meaning.

Lina, in panel 4:2, turns to the educational text, points at the last phrase: "carbon dioxide is produced" and proposes the formulation, "then it becomes carbon dioxide". Lina, by using the word "then" establishes a temporal order to the process. The expression: "carbon dioxide is produced" in the educational text is scientific language with a passive form. This way of describing a natural phenomenon in a passive metaphoric form is uncommon in everyday spoken language where something is caused by a preceding event (Halliday 2004). In other words, the students recast in a direct way what the text expresses with a 'grammatical metaphor' (ibid., p. 19).

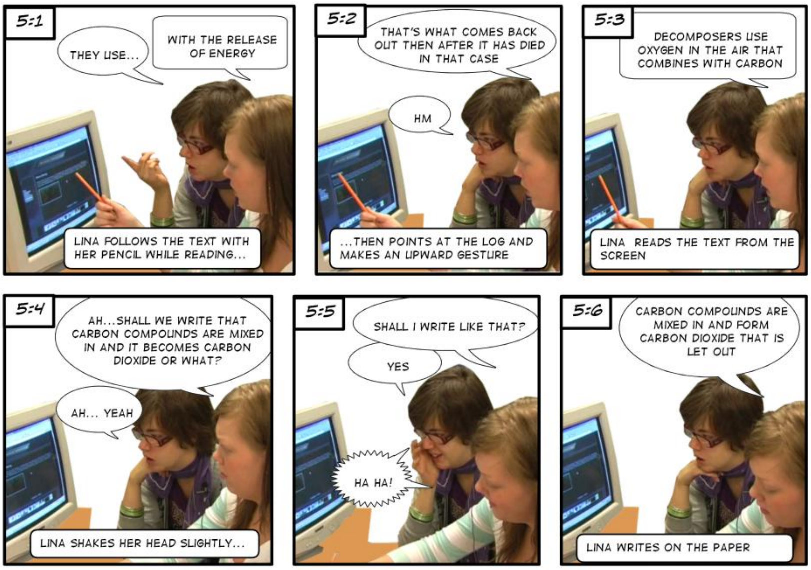
Lina, then again brings up the problem of formulating a written account by saying "how are we going to write this then" (4:3). After some consideration, she utters the word "oxygen" (4:4) and starts writing it down in the questionnaire. Kristi utters the verb "goes in" but Lina changes to the verb 'surround' when she says: "yeah oxygen surrounds the tree". For Lina, replacing the verb is obviously not a problem as she says "yeah" before her utterance, implying that "surrounds" has the same meaning as "goes in". Kristi accepts changing the verb without any protest. We can observe that once the agent subject (oxygen) has been agreed on, changing the verb is not an issue for the students. In episode 1 and panel 1:5, it was proposed that "oxygen goes onto" to in this episode be changed to "oxygen goes into" and "oxygen surrounds". This change of verb, though not problematic from a syntactic point of view, semantically implies that the subject 'oxygen' is given a different agency (Duranti, 2004).

In panel 4:5, Lina directs her attention to the educational text, points to the first sentence and quotes the phrase, “attacked by microorganisms”. The text says: “Dead plants and animals are attacked by microorganisms”. Lina, however, only quotes the second part of the sentence, “attacked by microorganisms” to link it with their observation of the moving oxygen molecules. Kristi says “yes that sounds good” (4:6), agreeing with Lina’s suggestion. Lina then writes down their first sentence: ‘*Oxygen surrounds the tree and is attacked by microorganisms’*. It is noteworthy that the first clause in the sentence is given an active form: ‘*Oxygen surrounds the tree*’ whereas the subordinate clause: “*is attacked by microorganisms*” is in the passive form. What they have visually observed in the animation is described in active form but the formulation derived from the educational text appears in its passive form. The active form in the main clause can be explained based on the assumption that when the agent (oxygen) is the subject, the clause is active (Tomlin, 1997). Their subordinate clause however, is taken from a scientific text where natural phenomena are often described in the passive form (Lemke, 1990; Halliday, 2004).

It can be observed in panel 4:1, 4.2 and 4:5 how Lina uses pointing gestures with her pen to make salient, for her companion, what features on the interface to attend to while she is speaking. This practice of “highlighting” structures of relevance on the screen can be seen as a method “used to divide a domain of scrutiny into a figure and a ground, so that events relevant to the activity of the moment stand out” (Goodwin, 1994, p. 610).

After completing their first sentence, the girls try to find out what else is happening in the process by once again scrutinising the educational text. In the next episode, we will follow their endeavour to reach a conclusion about what is happening in the mouldering process.

Episode 5



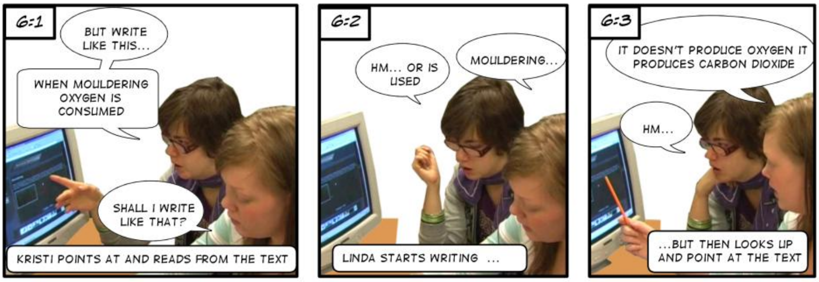
At first, both girls read the text silently with Lina following the lines with her pencil. Kristi suddenly points at the phrase: "these decomposers utilise" and exclaims "they use". Lina, however, does not follow up her companion's utterance and instead quotes the phrase "with the release of energy" from the text. In panel 5:2, she shifts her pencil from the text to the image of the decaying log and with an upward gesture demonstrates that something is coming out of the log and says: "that's what comes back out then after it has died". To an outside observer, it is not obvious what she means by "comes back"; whether she is referring to the "release of energy" in her previous remark or if she means the carbon dioxide shown emanating from the log in the animation. Lina's upward gesture with her pencil resembles the movement of the carbon dioxide in the animated sequence, which suggests that the animated structure is transplanted into iconic gesturing describing what is happening in the process.

Lina then (5:3) continues to read the text on the screen: "decomposers use oxygen in the air that combines with the carbon". After some contemplation, she asks, "shall we write that carbon compounds are mixed in and they become carbon dioxide" (5:4). With this suggestion, she reformulates what is expressed in the text as "combines with" as, in her own words becomes, "are mixed in". The term 'combines' is a rather abstract expression that involves a combination of at least two entities; in the educational text referring to chemical bonding. Lina's expression "mixed in" is, on the other hand, a plainer and more everyday phrase that simply means that you bring things together. The replacement of the verb "combines" with "mixed in" results in a change in meaning. This tendency, by the students, to replace verbs in the educational text with their everyday expressions results in that the meaning of the text also changes. For the students, who do not have access to the relevant subject knowledge, this changed meaning resulting from the replacement of the verb may not be obvious but results in their description diverging from a scientific explanation. In the scientific text, the forming of carbon dioxide is described in the passive form and it is noticeable that Lina's proposed formulation "carbon compounds are mixed in" is also constructed in the passive form. The usage of the passive form is a special feature of scientific language (Halliday, 2004; Lemke, 1990) that distinguishes it from colloquial language which describes events as causalities in an active form. However, there seems to be some disbelief in Lina's proposal, which can be discerned in ending her utterance with "or what" and slightly shaking her head.

Even though Kristi agrees, Lina disbelievingly asks again if she should "write like that" (5:5) whereupon Kristi again expresses her approval. After some laughing by both girls, Lina starts writing on the assignment sheet and says "carbon compounds are mixed in and form carbon dioxide that is let out" (5:6). With this description of "carbon dioxide that is let out" it is now evident that with the upward movement by her pencil in panel 5:2, Lina was referring to the carbon dioxide depicted in the animation as coming out of the log. Hence, what is described in the educational text as the process: "form carbon dioxide" becomes "let out" in Lina's interpretation of the animated molecules leaving the log. Her observation of the animated carbon dioxide molecules is given priority over the formulation in the educational text when she writes the report on the events.

While Lina is still concentrating on writing, Kristi again focuses her attention on the text by pointing at the screen.

Episode 6

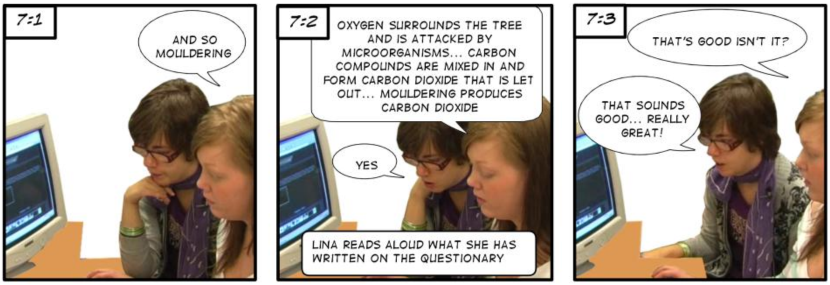


Kristi reads aloud from the text on the screen and suggests that they should write: "when mouldering oxygen is consumed". Lina responds by asking "shall I write like that". Kristi seems to perceive Lina's question as a problem of formulation and suggests rephrasing it by substituting the word "consumed" with her own expression "used" (6:2). Lina starts writing the word "mouldering" but suddenly looks up, points at the text (6:3), and raises the objection that "it doesn't produce oxygen it produces carbon dioxide". This could be seen as a strange comment on her companion's proposal of the formulation that "oxygen is used". Probably Lina is so involved in writing that she does not pay attention to Kristi's proposed formulation and misunderstands its meaning.

A really good account

The girls then read through their written accounts of all the processes again, finally coming back to the mouldering process. The turns when they go through the other processes have been omitted and we join them again when they return to their account of what is happening in the mouldering process.

Episode 7



In panel 7:2, Lina reads out loud what she has written down on their assignment sheet about what is happening in the mouldering process: "*Oxygen surrounds the tree and is attacked by microorganisms. Carbon compounds are mixed in and form carbon dioxide that is let out. Mouldering produces carbon dioxide*". We can now witness the formulation of the last sentence she has written in the questionnaire: *"Mouldering produce carbon dioxide"*. The formulation of this phrase was discussed by the girls in the previous episode but was not put into words by Lina until now. If we compare the formulation of Lina's sentence with the educational text: "When mouldering, oxygen is consumed and carbon dioxide is produced" we observe that the phrase: "oxygen is consumed" is omitted. Kristi wanted to reformulate this expression as oxygen "is used" (6:2), however, Lina did not include the phrase: "consumption of oxygen" in the account. Kristi nevertheless backs up Lina's formulation of their narrative by saying "yes" (7:2). Another observation that can be made is that what the educational text describes in the passive form: "carbon dioxide is produced", the students describe in the active form: *"Mouldering produce carbon dioxide"*. Again, we can observe the difference between the scientific passive form of grammatically describing an event with the students' description in the active form (Lemke, 1990).

Lina at finally asks, "that's good isn't it" (7:3) upon which Kristi answers "that sounds good, really good". Thus, the girls seem to be very satisfied with their account and this closes their dealings with describing the events in the mouldering process.

DISCUSSION

Taken together, the excerpts analysed give a picture of how the two students endeavour to find the logic in what is shown in the animation, matching it with the educational text and creating a story that makes sense from their point of view. They strive to make meaning out of the animation as well as the text and fit these two representations together in a written report.

Interpreting the animation and translating the educational text

The students start their interpretation of what is happening in the animated sequence by watching the oxygen molecules moving towards the decaying log. They also observe that when the oxygen molecules reach the log it turns dark. We can follow their descriptions of oxygen as the active agent throughout their discussion. In panel 1:5 "*oxygen goes onto the wood*", 2:4 "*but when those oxygen things reach it then it turns dark*", 2:6 "*yea exactly but oxygen shouldn't kind of get anything to rot*", 2:7 "*oxygen should help* *anyway*" and "*oxygen that went in there*"; 4:4 "*goes in*" (referring to oxygen) and "*oxygen surrounds the tree*". The perceptually salient features of the oxygen molecules being in motion attract the students' attention and the information they derive from the animation is driven by this dynamic effect (Lowe, 1999, 2003). Thus, the oxygen molecules become the active agent around which they create their narrative.

In the girls' attempts to explain what they observe in the animation, they turn to the educational text and try to construe it in a way that corresponds with what they observe in the animation. They read the text mostly silently but sometimes aloud, presumably when they want to stress something. In their effort to construct a story about what is happening in the mouldering process, they repeatedly strive to reformulate, in their own words, what is written in the educational text.

The students were supposed to explain what is happening in the different processes, but instead of telling their own story of what was happening in the mouldering process their actions turned out to make it a task of translating the given educational text into their own words. In the data we can find various types of support for that the girls engage in translation rather than telling their own story of what is happening in the mouldering process. First, they attend to the given sentences one by one, and while dealing with a particular sentence, they attend to its different elements in a similar step-by-step manner. Second, they collapse the second and the third sentence from the educational text into one. Third, the disconnected character of the girl's sentences for example, it is not at all clear whether the objects of the first sentence play any role in the second. Finally, in the follow-up interview where the girls were asked why they changed the words of the original text, one of the girls explicitly announced that it was to "show that we had done the assignment". The students' assignment was to explain what is happening in the mouldering process that was described in the educational software. Within the learning material, the animation and the educational text were the available resources for the students to draw on when accomplishing this assignment. Together with their observations from the animation of oxygen "surrounding" the trunk and with carbon dioxide "coming out" from it; the girls might have assumed that matching these observations with a translation of the educational text, assumed to give a correct description of the events, would result in the accomplishment of their task.

In a preliminary study (Karlsson & Ivarsson, 2008), it was shown how conflicting perspectives among the students aroused regarding how to formulate their reports. These conflicting perspectives were to some extent supposed to stem from the formulation of their task where it was pronounced that they should express themselves in their own words. The assignment for the students in this study did not state that they had to use their own words in their written account. Nevertheless, we can observe how the students attempt to find expressions that are dissimilar from the ones in the educational text and more in accordance with their own way of articulating the events. Even though we did not see the conflicting perspectives which are observed in the preliminary study on what kinds of resources the students were going to use, they tried to find their own expressions, not using the wordings in the educational text. This aspiration to express themselves in their own words influences their written account. When the girls were subsequently asked why they tried to find their own expressions instead of using the formulations in the educational text, their respective answers were: "*I wanted to express myself in my own words. I always try to use my own words in my answers"* (Kristi) and "*I think I reformulated the answer because if I wrote exactly as it said in the text on the computer I was afraid it wouldn't count as an answer, but cribbing so to speak. It wouldn't have shown that we had done the assignment even if what we did was just to reformulate it. I guess that's the reason*" (Lina). These statements express an underlying norm of articulating themselves in their own words when they are supposed to give an account in a school context, consequently there are "certain cultural conventions when approaching and solving tasks" (Lund & Rasmussen, 2008, p. 409).

The animation and the educational text together describe the mouldering process in two quite different modes; the animation by demonstrating moving molecules and the text by using scientific language. Both of these modes describe the metabolism occurring inside microorganisms. The students' meaning-making process is taking place in their attempt to grammatically construct a narrative from two different semiotic resources. With the help of the educational text, they then strive to explain in their everyday language what they can see happening in the animation.

Framing their sentences

When the students begin writing their report, they start with: "*Oxygen surrounds the tree*". Being perceptually salient, the oxygen molecules first caught their attention. To find a cause of this motion towards the log, the students turn to the text and find the phrase "*attacked by microorganisms*", which becomes the second clause. Their first sentence is then: "*Oxygen surrounds the tree and is attacked by microorganisms*". If we look at how the students have grammatically constructed their narrative of what is happening in the animated sequence, oxygen is ascribed the role of the active semantic agent that 'surrounds the tree' and then 'is attacked' by microorganisms.

The main clause "*Oxygen surrounds the tree*" is framed by an 'agentive' instigator (oxygen) of the action and an 'objective' (the tree) affected by the action. Hence, the *noun phrases*, 'oxygen' and 'the tree' are associated in their specific case relationship, in the frame feature for the verb 'surround' (Fillmore, 1968). However, this description is not in accordance with the wording in the captioning text where it says that: "Dead plants and animals are attacked by microorganisms". The animate microorganisms are described in the educational text as the active subject, attacking dead materials. In the students' construal of the animation, the inanimate oxygen molecules take over the role of an active subject from the animate microorganisms. This shift of agency and subject role, from the animate 'microorganisms' to the inanimate 'oxygen', can be attributed to two different phenomena. First, the character of the animation that makes the oxygen molecules perceptually salient. Second, the grammatical rules in Swedish (as well as in English) that allows inanimate objects to be given an agentive status. As expressed by Duranti (2004): "We should take into consideration the possibility that, by representing actions and events typically generated by human beings *as if* they were generated by inanimate objects or abstract sources, English speakers might be giving these non-human entities a quasi-agentive status." (p. 464).

Hence, the character of the animation furnishes the otherwise inanimate oxygen molecules with an active role as they are observed moving towards the log. Contrary to real events in nature, an animation can provide inanimate objects with qualities such as motion and directionality. In the animated sequence, the oxygen molecules are given locomotive power as well as a directional course owing to the visualisation of a scientific phenomenon. In addition, the temporality of the events in the animation, where simultaneous events are sequentialised and oxygen appears as the first moving object, makes them prominent (Lowe, 2003). Thus, events that occur simultaneously tend to be visualised in sequence due to the unfolding character of the animation. These qualities of the animation taken together make the oxygen molecules active and 'attentionally detected' and, therefore, the subject (Tomlin, 1997, p. 175) in the students' description.

In their first sentence: "*Oxygen surrounds the tree and is attacked by microorganisms*" the students copied the subordinate clause "*is attacked by microorganisms"* from the educational text where the word 'attacked' refers to the microorganisms' consumption of energy-rich carbon hydrates in organic material. This phrase fits grammatically into the sentence frame

(Fillmore, 1968), however, with this construction, the phrase "*is attacked by microorganisms*" refers to the inorganic 'oxygen'. The term 'attacked' is in itself problematic when used in an educational text as it implies agency in the phenomenon described. On the one hand, from an educational point of view, it communicates the microorganisms' process of breaking down carbon hydrates into organic matter. On the other hand, the agency implied by the term 'attacked' is unintentionally taken up by the students to describe what happens to the oxygen molecules. Thus, the students' construction of the sentence results in an unintended description of what is happening in the process.

The students' formulation of the second sentence: "*Carbon compounds are mixed in and form carbon dioxide that is let out*", like their first sentence, would not be acceptable from a scientific point of view. In their construction of this sentence, the girls looked through the educational text and from the sentence: "With the release of energy, the decomposers use oxygen in the air that combines with the carbon in the carbon compounds and forms carbon dioxide." they picked out the noun 'carbon compounds' that were given the subject role. Having chosen the subject, they continued and tried to find a verb describing what happens to the 'carbon compounds'. In the same sentence in the educational text, they found "combines" that they reformulated as 'mixed in'. They had then formulated their main clause: "*Carbon compounds are mixed in*". When forming the subordinate clause, they took the phrase "and form carbon dioxide" from the same sentence in the educational text. This phrase was then combined with the verb 'let out', which was derived from the students' construal of the animation where carbon dioxide molecules were seen leaving the log. Their sentence was then completed as "*Carbon compounds are mixed in and form carbon dioxide that is let out*". This second sentence also fits into a sentence frame although it does not give an explanation of the event that can be in accordance with a scientific description.

When constructing their narrative about what happens in the process, the students strive to find a noun phrase (NP) that is followed by a verb that fits into a sentence frame. "In English, when present, the NP with the Agent role is typically chosen to be the subject" (Duranti, 2004. p. 460). In the students' effort to using their own words, they try to find verbs that are different from the ones in the educational text. Grammatical rules allow the verb to be changed within the sentence frame (Fillmore, 1968; Duranti, 2004). However, in the process of changing the verb they may also alter the agency of the subject. These courses of action together, contribute to giving the students' report on what happens in the mouldering process the character of a non-scientific explanation. Lacking definite access to the relevant subject matter knowledge, the students consequently cannot judge whether they have given an acceptable account. The only way they have to appraise their written report is to check if it "sounds good", which they do by reading through their written report. By using noun phrases, taken either from the animation or from the educational text as agentive subjects and with self-constructed verbs, they created a grammatically correct although not scientifically correct written report of the mouldering process.

The students judged their account of the depicted process to be "good" or even "really good", which made them satisfied with their task. The analysis shows that the students have actually made an effort when constructing a shared meaning and writing a comprehensible report. Seen from the students' point of view and with the resources available to them, they created an acceptable narrative of the events described in the software. However, according to their teacher's judgment "they demonstrate a great lack of knowledge" and "they only have some understanding of mouldering". Before their work with the animation, the two girls said that they were "not at all good at science and that stuff". They will certainly be disappointed when they learn of their teacher's criticism of their account. This will probably also reinforce their conviction that they are not good at science and that science is a difficult topic to understand. Consequently, providing students with animations of scientific phenomena and giving them the task of discovering scientific processes without sufficient guidance, may run the risk of leading them away from the intended learning outcome and giving them the impression that science is a difficult subject and hard to master.

"Size and animacy (or at least motion) represent—completely independent of language—characteristics of objects which attract attention" (Tomlin, 1997, p. 182) When having to represent the animated event "large size or animacy may simply result in a particular attentional detection, and it is this which is mapped onto subject" (ibid., p. 182). In the students' construal of the animation, the animacy of the gas molecules, especially the oxygen molecules, influenced their description of the events. This feature of the animation resulted in the oxygen molecules as agent subjects becoming more or less fixed, giving less freedom to create innovative explanations. Instead, the freedom to construct a narrative lay in their grammatical choices of verbs. In the educational text, the students also found expressions such as "Dead plants and animals are attacked" and "the decomposers use", which introduces agency into the process they have to report. The use of a word such as "attacked" and the agency described in their account must therefore be seen in relation to the formulation of the educational text. However, what makes their report diverge from a scientific description of the mouldering process is not the active form as such, but more that the agency is attributed to other subjects than those intended.

CONCLUDING REMARK

This study demonstrates, like other similar studies (e.g., Teasley & Roschelle, 1998), that animated computer software has the potential to engage students in a joint problem-solving activity that results in shared meaning-making of the visualised events. More interesting, however, is the fact that the results also point to the problem that students' interpretation of an animated scientific phenomenon is no guarantee of the intended learning outcome, even though prepared in a preceding lesson and accompanied by an educational text. The students in this study constructed a narrative describing the observed events and drew on resources from the following: characteristics of the animation as agency and temporality, the accompanying educational text where activity and intentionality were expressed, and their earlier experience and everyday language. Without sufficient background knowledge of the subject matter, the students' conclusion runs the risk of being deemed an incorrect description of the phenomena depicted. This shows that an unguided construction of meanings from an animation runs the risk of leading to unintended and, hence, unscientific concepts. Joint meaning-making of an animated scientific phenomenon does not automatically lead to the concept constructed by the learners being in accordance with what is intended. Thus, when designing and using educational software for school activities, in order to provide an understanding of scientific concepts, it is important to consider both cultural and semiotic processes.

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REFERENCES

Arnseth, H. C., & Ludvigsen, S. (2006). Approaching institutional contexts: systemic versus dialogic research in CSCL. International Journal of Computer-Supported Learning, 1(2), 167-185.

Brown, A. L. (1992). Design experiments: Theoretical and Methodological challenges in creating complex interventions in classroom settings. The Journal of the Learning Sciences, 2(2), 141-178.

Cañal, P. (1999). Photosynthesis and 'inverse respiration' in plants: an inevitable misconception? International Journal of Science Education, 21(4), 363-371.

Chittleborough, G. D., Treagust, D. F., Mamiala, T. L., & Mocerino, M. (2005). Students' perceptions of the role of models in the process of science and in the process of learning. Research in Science & Technological Education, 23 (2), 195-212.

Duranti, A. (2004). A companion to linguistic anthropology. Malden, MA: Blackwell Pub.

Eisner, W. (1985). Comics and sequential art. Tamarac: Poorhouse Press.

Fillmore, C. J. (1968). The case for case. In E. Bach & R. T. Harms (Eds.), Universals in linguistic theory. N Y: Holt, Rinehart and Winston, Inc.

Goodwin, C. (1994). Professional Vision. American Anthropologist, 96(3), 606-633.

Greiffenhagen, C., & Watson, R. (2007). Visual Repairables: analyzing the work of repair in human-computer interaction. Forthcoming in Visual Communication.

Grosslight, L., Unger, J., Jay, E., & Smith, C. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. Journal of Research in Science Teaching, 28(9), 799-822.

Halliday, M. A. K. (2004). The language of science. London: MPG Books Ltd.

Ivarsson, J. (in press). Developing the construction sight: Architectural education and technological change. Visual Communication, 9(4).

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The Journal of the Learning Science, 4(1), 39-103.

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

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: expert and novice responses to different representations of chemical phenomena. Journal of research in science teaching 34(9), 949-968.

Krange, I., & Ludvigsen, S. (2008). What does it mean? Students' procedural and conceptual problem solving in a CSCL environment designed within the field of science education. International Journal of Computer-Supported Collaborative Learning, 3, 25-51.

Kuech, R., Zogg, G., Zeeman, S., & Johnson, M. (2003). Technology Rich Biology Labs: Effects of Misconceptions. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Philadelphia, PA, March, 2003), Available online.

Lemke, J. L. (1990). Talking science—Language, leaning, and values. London: Ablex.

Lemke, J. L. (1998). Analysing verbal data: Principles, methods, and problems. In K. Tobin & B. Fraser (Eds.), International Handbook of science education (pp. 1175-1189). Boston: Kluwer.

Lemke, J. L. (2006). Towards critical multimedia literacy: technology, research, and politics. In M. McKenna, L. Labbo, R. Keiffer & D. Reinking (Eds.), Handbook of Literacy and Technology (Vol. 2, pp. 3-14). N Y: Erlbaum (LEA Publishing).

Lindwall, O. (2008). Lab work in science education. Linköping: Linköping Universtiy.

Lowe, R. K. (1999). Extracting information from an animation during complex visual learning. European Journal of Psychology of Education, 14(2), 225-244.

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. Learning and Instruction, 13, 157-176.

Lund, A., & Rasmussen, I. (2008). The right tool for the wrong task? Match and mismatch between first and second stimulus in double stimulation. International Journal of Computer-Supported Collaborative Learning, 3(4), 387-412.

McCloud, S. (1994). Understanding Comics. The invisible art. New York: HarperPerennial.

Morton, J. P., Doran, D. A., & MacLaren, D. P. M. (2008). Common Student Misconceptions in Exercise Physiology and Biochemistry. Advances in physiology education, 32(2), 142-146.

Sanders, M. (1993). Erroneous ideas about respiration: The teacher factor. Journal of Research in Science Teaching, 30(8), 919-934.

Smith, C., Maclin, D., Grosslight, L., & Davis, H. (1997). Teaching for understanding: A study of students' pre-instruction theories of matter and a comparison of the effectiveness of two approaches to teaching about matter and density. Cognition and Instruction, 15(3), 317-394.

Stahl, G. (2006). Group cognition: computer support for collaborative knowledge building. Cambridge: MIT press.

Säljö, R. (1998). Thinking with and through artifacts: The role of psychological tools and physical artifacts in human learning and cognition. . In D. Faulkner, K. Littleton & M. Woodhead (Eds.), Learning relationships in the classroom. London: Routledge.

Teasley, S. D., & Roschelle, J. (1998). Constructing a Joint Problem Space: The Computer as a Tool for Sharing Knowledge. Retrieved from http://ctl.sri.com/publications/downloads/JointProblemSpace.pdf

Tomlin, R. S. (1997). Mapping conceptual representations into linguistic representations: The role of attention in grammar. In J. Nuyts & E. Pedersen (Eds.), Language and conceptualization (pp. 162-189). Cambridge: Cambridge University Press.

Wegerif, R. (2007). Dialogic Education and Technology: Springer Verlag.

Wertsch, J. V. (1991). Voices of the mind. A sociocultural approach to mediated action. Cambridge, MA: Harvard University Press.

Vygotsky, L. (1934/1986). Thought and language. Cambridge, MA: The MIT Press.

This thesis is inspired by the prospect of using computer technology for enhanced learning in science education. Digital learning materials offer novel ways of illustrating invisible scientific concepts. The overall aim with the research was to study students' practical problems of understanding the computerised learning material.

For the purpose of the research project a computer animated display of molecular processes involved in the carbon cycle was created. In two successive studies, secondary school students' interaction with each other and with the learning material was analysed. Results from the studies evince how salient features in the animated displays direct the learners' interpretation of the described phenomena. Without specific access to the knowledge domain the students' descriptions of the process run the risk of diverting from the intended, scientific concept.

It is concluded that there are no straightforward ways in students' interpretations of animated learning material. Important aspects to consider, when applying digital learning material, are teacher guidance, educational framing and semiotic processes that influence how learners understand and describe the depicted events.

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