ELISABET M. NILSSON

SIMULATED "REAL" WORLDS

Actions mediated through computer game play in science education

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To Agneta and Claes-Göran

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I hope you will enjoy taking part of the ideas presented in this thesis, and please, come back to me with your thoughts and comments.

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SETTING THE SCENE

Over the last decade, a great variety of visionary ideas, and beliefs have been brought forward regarding the educational potentials of using computer games[i] as a tool[ii] for learning and mediation in educational settings (e.g. overviews in De Freitas, 2007; Egenfeldt-Nielsen, 2006; Kebritchi & Atsusi, 2008; Kirriemuir & McFarlan, 2004; Linderoth et al., 2002; Mitchell & Savill-Smith, 2004; Susi et al., 2007; Williamson, 2009).

This thesis aims at contributing to the research in this field by empirically exploring what happens *in situ* when students collaboratively play and reflect on their computer game play in a science learning context. Three empirical studies and a research review have been conducted. The first study was a part of a design-based research project on mobile learning, and involved students playing the mobile educational game *Agent O* (Fergusson et al., 2006). The two following studies involved students playing the commercial off-the-shelf (COTS) computer game *SimCity 4* (Maxis, 2003), in connection with the annual Swedish school competition Future City (Future City, 2008).

This work is not *about* science education. Instead it studies actions mediated by computer games, and possible implications *for* science education. The focus is on *mediated actions* that emerge during *computer game play* and their potential relevance to school science learning. Findings may add to the discussion on ways computer games can play a role in science education.

Two tendencies are important as a background to the thesis. *Firstly*, the rapidly increased use of digital media among young people (Mediappro, 2006; Roberts et al., 2005; Swedish Media Council, 2008). *Secondly*, the challenge digital media pose for education (Klopfer, 2008; Linderoth, 2009a; Selander, 2008; Shaffer & Clinton, 2006; Sørensen et al., 2007).

The increased use of digital media is illustrated by the spread of computer game play, which today is a significant social and cultural activity in society. In Sweden, nearly all boys (96%), and more than two thirds of the girls (71%) aged 9–16 play computer games (Swedish Media Council, 2008). In the rest of Europe, we find similar figures. Almost two thirds of young people[1] aged 12–18 play games on PC's, and half of them on game consoles (Mediappro, 2006). A North American report shows that US youth aged 8–18 spend in average 49 minutes a day playing computer games (Roberts et al., 2005). The same study demonstrates that young Americans spend an increased amount of time consuming new media, such as computer games and the Internet, but without decreasing time spent with "old" media, for example TV, music, books. Instead, they tend to use several media simultaneously, playing computer games at the same time as watching TV, chatting while doing home work, listening to music etc. As pointed out by Williamson (2009), despite these figures based on statistics, we should be careful to presume that computer game play has already become a natural part of young people's lifestyle. Not *all* young people play computer games, even though that sometimes this might be the impression when reading articles and reports.

The issue of gradually declining results on science tests, and the problem of motivating students to study science are well established in most Western countries (OECD, 2006). Science as part of modern society is seen as valuable and interesting, but the students themselves express that science as a school subject lacks both personal and social relevance (Jidesjö & Oscarsson, 2006; Lindahl,

[1] Teenagers from Belgium, Denmark, Estonia, France, Greece, Italy, Poland and the United Kingdom participated in the study.

2003; Oscarsson et al., 2009). Digital media, like computer games, are rarely used in science classrooms, even if the potential of designing learning interventions involving computer game play is vividly discussed. Claims brought forward suggest that the intrinsic learning qualities of computer games make them into powerful educational tools that can be used to organise formal learning activities (e.g. Egenfeldt-Nielsen, 2007; Ekenberg & Wiklund, 2009; Klopfer, 2008; Magnussen, 2008; Svingby & Nilsson, Submitted). The technology in itself may, however, not make any difference, as Cuban underlines (2001). It is not until technology is used in a meaningful educational situation that it might contribute to better learning.

The problems encountered in science education, and the expanding use of computer games outside of schools have made educational researchers challenge the ability of the educational system to accommodate the conditions caused by the introduction of new mediating tools (e.g. Klopfer, 2008; Selander, 2008; Shaffer & Clinton, 2006; Sørensen et al., 2007). It is argued that current models for learning are based upon old structures that were valid in a previous industrial era when other kinds of tools were available, and that the new generation of learners has different needs and demands. The arguments are based on a contextualised and situated view on human learning implying that educational systems have to take the students' own worlds in account if they want to reach out to them (e.g. Lave & Wenger, 1991; Linderoth, 2009a; Säljö, 2005). As stated by Gee (2003), to learn and develop "is not just a matter of what goes on inside people's heads but is fully embedded in (situated within) a material, social and cultural world" (p. 8).

A problem is, however, that empirically based research results demonstrating the educational potentials of computer game play are sparse, and that most of the findings presented so far are based upon theoretical assumptions (e.g. Egenfeldt-Nielsen, 2007; Hanghøj, 2008; Linderoth, 2004; Wong et al., 2007). Thus, this does not imply that the educational use of computer games is unexplored, only that "research evidence is complex and thinly spread" (Kirriemuir & McFarlane, 2004, p. 3). Many questions remain unanswered "largely due to the fragmented nature of the research into the educational use of computer games and the lack of throughout case studies" (Egenfeldt-Nielsen, 2007, p. 5). This thesis aims to shed light on some of these areas, where empirical research, so far, has been relatively fragmentary.

Outline of the thesis

The thesis is divided into two parts. Part one consists of six chapters. Chapter one, *Setting the scene*, presents points of departure, focus, and an outline of the thesis. The second chapter presents the *Theoretical perspective* that guides this work and the approach suggested for analysing actions mediated by computer games. The chapter also presents ideas behind the Socio-scientific issues (SSI) framework, as well as educational potentials of computer game play presented by previous research. The third chapter presents the *Aim and research questions* explored. The fourth chapter, *Methodology and research design,* discusses methodological concerns, choice of research design, including techniques of data gathering and data analysis. A description of the research process is also provided, clarifying how the studies relate to each other, as well as a descriptive analysis of the two computer games played. The fifth chapter presents a *Summary of papers I–IV*. The last chapter, *Discussion*, addresses a selection of themes, in relation to the overarching aim and research questions.

Part two consists of the following studies presented in four papers published (or to be published) in external peer-reviewed publications.

Paper I:
Gaming as actions: students playing a mobile educational computer game
Co-author: Gunilla Svingby
Published in *Human IT*, 10(1), 26–59

Paper II:
Simulated sustainable societies: students' reflections on creating future cities in computer games
Co-author: Anders Jakobsson
Accepted with revisions for publication in the *Journal of Science Education and Technology*

Paper III:
Simulating a "real" world or playing a game? COTS games played in the science classroom
Co-author: Gunilla Svingby
Accepted for publication in *IDM and VR for Education in Virtual Learning Environment* edited by Yiyu Cai, Nova Sciences Publishers, New York

Paper IV:
Research review: empirical studies on computer game play in science education
Co-author: Gunilla Svingby
Under review by the *Handbook of Research on Improving Learning and Motivation through Educational Games: Multidisciplinary Approaches* edited by Patrick Felicia, IGI Global, Hershey

The papers are printed with permission from the publishers.

THEORETICAL PERSPECTIVE

The theoretical perspective chosen to inform and guide the studies performed in this work is based upon a *socio-cultural* view of human action and learning (e.g. Lave & Wenger, 1991; Lemke, 2001, 2002; Säljö, 2005; Wertsch, 1991, 1998). There is no single socio-cultural theory, but rather a rich variety of directions (Wertsch, 1998). The variations are based on different theoretical traditions, most of which derive from the writings of the Russian psychologist and educator Lev Vygotsky (e.g. 1987). Following the Vygotskyan tradition, Wertsch describes the task of socio-cultural analysis as "to explicate the relationship between human *action* [learning included], on the one hand, and the cultural, institutional, and historical contexts in which this action occurs, on the other" (Wertsch, 1998, p. 24).

The following chapter aims at introducing an approach that may be used for analysing actions mediated by computer games, and for positioning the present work in a societal and cultural context. A presentation of the theoretical perspective chosen is provided, starting out from the fundamental ideas of Vygotsky (1987), and further refined and extended by Bruner (1965, 1966), Lave and Wenger (1991), Lemke (2001, 2002), Wertsch (1991, 1998), and Säljö (2005), among others. Three basic assumptions are highlighted, namely the assumptions that *learning is situated*, *tools are carriers of culture,* and *actions are mediated by tools*. Emphasis is placed on the last assumption, since the unit of analysis of this work is *mediated actions*.

Also, science education research is considered, specifically research related to the ideas behind the *Socio-scientific issues* (SSI) framework, advocating a contextualised view on science learning (Aikenhead, 2006, 2007; Zeidler, 2007). It is suggested that to learn science, students should engage in *scientific practice*, including use of scientific concepts and theories, applying these in scientific inquiry processes that are connected to actual societal concerns, and situated in real world situations (Lemke, 1990). Recent socio-cultural research on computer game play in education is briefly described (e.g. Gee, 2003; Egenfeldt-Nielsen, 2007; Linderoth, 2004, 2009; Shaffer & Clinton, 2006), in particular research focusing on science education (e.g. Aitkin, 2004; Barab et al., 2007, 2007a; Klopfer, 2008; Squire & Jan, 2007).

A contextualised view on human action and learning

Learning is situated in societal and cultural contexts

According to a socio-cultural view, human action and learning cannot be extracted from the context in which it occurs (Lave & Wenger, 1991). An emphasis is put on the *situatedness* of learners, as well as the importance of *enculturation*. This is referred to as the process when individuals "come to understand, appropriate, and appreciate the values, norms, and practices of a group" (Sadler, 2007, p. 87), and become a part of that community (social practice), with all that that implies. Basically, "*what* we learn is how to live successfully in a world of other people, and *how* we learn is by participating in the activities of our community" (Lemke, 2002, p. 35).

The fundamental assumption is that learning processes are different, depending on what community we are associated to, as well as on what tools and resources are available for us to utilise (Säljö, 2005; Wertsch, 1991, 1998). In our Western society it is quite obvious that we make use of certain tools, and learn and apply our knowledge in certain ways. For example, a person living in an urban environment is most unlikely to learn how to manage a bow for hunting, since that kind of competence is not required for life in a modern city. On the other hand, it is probably required of that same person to be able to run a computer, browse through the Internet, and maybe have an idea of what a computer game is, since these are tools that are applied and referred to in most technologically developed societies.

Tools are carriers of culture

Consequently, human actions and learning processes are intertwined in, and dependent on, the surrounding culture. They depend on how knowledge and resources are shared and mediated via sets of tools available in that particular community (Säljö, 2005; Wertsch, 1991, 1998). Both the practice in *making* the tools and *using* them are passed on, and improved upon from one generation to the next (Wells & Claxton, 2002). The growth of mind is a process assisted from "outside" the individual, and "the limits of growth depend on how a culture can assist the individual to use such intellectual potentials as he [or she] might possess" (Bruner, 1965, p. 1007).

Tools – for example, a book, a data base, or digital networks – influence how previously gathered knowledge in society is codified, stored and transferred. To access sources of knowledge embedded in certain tools, the individual has to learn how to handle these tools. To take a simple example, not knowing how to use a search engine on the Internet, makes it impossible to access information available about a specific topic. Which kind of competences are appropriate, or required to access resources embedded in certain tools, is a matter that changes over time, and is connected to the introduction of new technologies (Bruner, 1965). Human learning processes are thus not just dependent on individual knowledge or skills, or the ability to collaborate, but are also distributed across available tools, and the capability to access them (Wells & Claxton, 2002). A central question is how emerging tools in contemporary society influence how sources of knowledge are being shared and transferred between individuals, and thereby assist actions and learning processes?

Actions are mediated by tools

It is argued that our thoughts are created and developed depending on the tools we use, or have access to. “Higher mental functioning and human action in general are mediated by tools (or ’technical tools’) and signs (or 'psychological tools)” (Wertsch, 1991, p. 28), and processes like remembering, problem-solving, or being creative, are tightly connected to the tools applied. The tools enable us to do, experience, and learn things that we cannot achieve without them (Säljö, 2005). Throughout history, mankind has developed different sets of tools that bring us beyond our original physical and mental abilities. We have built vehicles that can transport us from one part of the world to the other in less than a day. The usage of external memory systems, such as books and data bases, relieves the pressure on our own memory system. The invention of digital networks makes it possible for us to communicate with people outside the local community, or to in real time plan a complex action with physically remote fellow gamers in multi-player online games. These examples illustrate some of the ways in which we have compensated for our insufficient biological abilities, by developing a range of tools and aids that support and make our desired actions possible to achieve (Säljö, 2005; Wertsch, 1991, 1998).

Human action “employs ‘mediational means’, such as tools and languages, and these mediational means shape the action in essential ways” (Wertsch 1991, p. 12). When observing a person solving almost any kind of problem, from mathematical problems to how to bake a cake, various tools are being applied that the thinking is supported and influenced by. Thus, the usage of tools is intertwined with the mental process that is taking place. There is a *dialectic* relationship between actions and tools, which is essential in understanding learning (Burke, 1969; Säljö, 2005; Wertsch, 1998). That is, actions are mediated and influenced by the tool, and at the same time, by using the tool, the understanding of how it may be used increases. This might change the way the tool is being used, and consequently, the actions that are taking place.

Dramatistic approach towards human action
Wertsch (1998) applies the ideas of the literary theorist and philosopher Burke (1969) for analysing tools in relation to action. Burke's primary interest lies in rhetoric and aesthetics, but his *dramatistic approach* towards human actions, putting an emphasis on the relationship between the motive and the action, is also applicable when analysing learning situations.

Burke (1969) argues that most human actions can be approached as a drama. This means that they are understood in terms of a *pentad*, and as an outcome of the *pentadic* elements: *act, scene, agent, agency,* and *purpose*. Burke suggests that the *dramatistic pentad* be used to generate principles to investigate the relationship between motives and actions, and how tools influence actions and vice versa. These perspectives can be formulated as questions, and applied as a method for exploring the relationship between the elements:

Act: names what is taking place, in thought or action – what happened, what is going on?

Scene: the background of the act, the situation in which it occurs – where is the act happening, what is the background situation?

Agent: humans involved – who is involved in the action, what are their roles?

Agency: the tools used – how do the agents act, by what means do they act?

Purpose: goal of the act – why do the agents act, what do they want?

Both Wertsch (1998) and Burke (1969) admit the difficulties of investigating actions, and see analytical efforts directed towards any single element in isolation as misguiding. To avoid the pitfalls of reductionism, Wertsch (1998) suggests an approach involving *mediated actions* as unit of analysis. In line with this suggestion, the present work does not aim to study the individuals, the environment or the tools in isolation, but instead focuses the complex unit composed by individuals acting with the tools in the environment.

Mediated actions

Wertsch describes mediated action as "agent-acting-with-mediational means" (Wertsch, 1998, p. 24). Mediated action is described as a *process,* involving the potentials of tools to shape actions, and how humans make use of these potentials in a particular situation. In line with Burke (1969), Wertsch states that the study of mediated actions involves *humans* (agent) and their *tools* (agency), that is, the mediators of actions. Compared to Burke however, he puts less focus on the elements *scene*, and *purpose*. Wertsch argues that it makes sense to give the relationship between human and tools a privileged position, for several reasons.

Firstly, he claims that to focus on the *dialectic* tension between the human and tool is maybe the most direct way to avoid limitations of methodological individualism. It forces us to go beyond the individual agent, when trying to understand the forces that shape actions. Secondly, to study mediated actions by looking at humans and tools also provides important insights into other dimensions of the pentad. This is because the other pentadic elements (act, scene, purpose) are often shaped, or even created by mediated actions. Wertsch (1998) also notes that to study mediated actions provides a "natural link between action, including mental action, and the cultural, institutional, and historical contexts in which such action occurs" (p. 24). He states this is so because tools are inherently situated – culturally, institutionally, and historically.

According to the view elaborated on here, almost all human actions are mediated, and thus not limited to physical, bodily actions. Mediated action also includes speech, and thoughts. There would not be much point in attempting to develop a comprehensive list of action forms and tools, of course, but Wertsch (1998) has outlined a set of basic claims that characterise mediated actions and tools[1]. His ten claims are: "(1) mediated action is characterized by an irreducible tension between agent and mediational means; (2) mediational means are material; (3) mediated action typically has multi-

[1] In the quote Wertsch uses the terms "agents" for "humans", and "mediational means" for "tools".

ple simultaneous goals; (4) mediated action is situated on one or more developmental paths; (5) mediational means constrain as well as enable action; (6) new mediational means transform mediated actions; (7) the relationship of agents towards mediational means can be characterized in terms of mastery; (8) the relationship of agents towards mediational means can be characterized in terms of appropriation; (9) mediational means are often produced for reasons other than to facilitate mediated action; and (10) mediational means are associated with power and authority" (p. 25). These aspects ought to be taken in consideration when exploring mediated actions emerging during computer game play in school.

Actions mediated by tools in contemporary society
Assuming the theoretical perspective presented above, it can be stated that the competences individuals have to appropriate in order to navigate in society are in a constant flux, depending on the tools available. Currently, our society is witnessing an immense development of information and communication technologies, and mediating tools of various kinds (Castells, 2007; Jenkins, 2006; Säljö, 2005). The question of how the introduction of technologies influences human action, how it changes and develops society – including education – is of course nothing new. In all times, we have influenced, or been influenced by the arrival of new technologies, and there are many examples of how this has changed prerequisites for everyday life (Castells, 2007; McClellan & Dorn, 2006; McLuhan, 1964).

Jenkins (2006) has made an attempt to sketch out what characterises the generation that has grown up surrounded by mediating tools, such as digital media and interactive and visually driven learning environments; computer games, chat rooms, programmes for instant messaging, wikis, blogs, and other social software applications. He states that most discussions about the emergence of new mediating tools have had a focus on technologies. Instead of talking about the characteristics of the technology, Jenkins focuses on the concept of *participatory cultures*, since participation is a property of culture. Jenkins argues that a "[p]articipatory culture is emerging as the culture absorbs and responds to the explosion of new media technologies" (Jenkins, 2006a, p. 8), such as online communities, social networks, computer game worlds. Many people are already a part of this process through:

"*Affiliations* – memberships, formal and informal, in online communities centered around various forms of media, such as Friendster, Facebook, message boards, metagaming, game clans, or MySpace).
Expressions – producing new creative forms, such as digital sampling, skinning and modding, fan videomaking, fan fiction writing, zines, mash-ups).
Collaborative Problem-solving – working together in teams, formal and informal, to complete tasks and develop new knowledge (such as through Wikipedia, alternative reality gaming, spoiling).
Circulations – Shaping the flow of media (such as podcasting, blogging)" (Jenkins, 2006a, p. 8).

Over the last years, a large number of communities and services have been launched, based upon this emerging participating and contributing culture. They are all examples of collaboration on a large scale, about bringing together the small contributions of millions of people, and to no longer be dependent on some individual genius to provide solutions. Jenkins also elaborates on the expression *collective intelligence* (Lévy, 2000), referring to a by-technology-enabled network society, where people form knowledge communities to solve problems that they cannot solve on their own (e.g. wikis, game clans, social web applications). In this kind of environments, the world is looked upon as a place where no one knows everything, but together the collective knows a lot. This view changes the way information is used and gathered, while the image of the information provider as being a single person loses its relevance. Such participatory cultures may open for participants not only to be receivers and readers of information and messages, but also producers and contributors. It may, however, also open for interactions on a surface level, or/and individuals not taking part seriously, but assuming a passive approach (e.g. Malmberg, 2006; Johnsson, 2009).

To sum up, when reflecting upon the effects of these few examples, the assumption that tools are *active* objects, influencing how we think, act, and behave (Wertsch, 1991, 1998), becomes concretely evident. The emergence of new technologies and mediating tools can both be seen as *consequences of*, and at the same time *vehicles for* cultural and societal change (Jenkins, 2006; Shaffer & Clinton, 2006). This changes the standards for *what*, and *how* knowledge is acquired, and puts new demands on the educational system (Klopfer, 2008; Selander, 2008; Selander & Svärdemo-Åberg, 2009; Shaffer & Clinton, 2006). The current post-industrialised society is at a stage of change that requires a new understanding of learning processes and knowledge production (Selander, 2008; Sørensen et al., 2007; Wells & Claxton, 2002).

Educational potentials of computer game play in science education

Today the majority of Swedish teenagers play computer games, and engage in game culture (Swedish Media Council, 2008). It has been pointed out that computer games and other digital media with interactive and visually driven learning environments are challenging the traditional modes of communication more commonly applied in school (Gee, 2007; Klopfer, 2008; Shaffer, 2007). It is claimed that computer games provide a favourable environment for good learning experiences, since "they lower the threat of failure; foster a sense of engagement through immersion; sequence tasks to allow early success; link learning to goals and roles; create social context; are multi-modal; support early steps into a domain" (Dibley & Parish, 2007, p. 35). Gee (2003) even argues that features of well-designed computer games "fits better with the modern, high-tech, global world today's children and teenagers live in than do the theories (and practices) of learning that they see in school" (p. 7). At the same time, it is also claimed that learning processes taking place during computer game play are driven by different motives than school learning activities, and we should be careful to place these learning practices on an equal footing (Linderoth, 2009).

Still, the fact is that there is a growing interest in using computer games for educational purposes, and investigating in what ways computer game play can be used for organising learning activities (Klopfer, 2008; Sørensen, 2009). As put forward in the introduction, the potentials of using computer games as a tool for learning and mediation in education have increasingly become a subject of research in later years. This thesis does not aim at presenting a comprehensive overview of previous research on computer games and learning, since that information already has been well discussed, and published elsewhere (see e.g. overviews by De Freitas, 2007; Egenfeldt-Nielsen, 2006; Kebritchi & Atsusi, 2008; Kirriemuir & McFarlane, 2004; Linderoth et al., 2002; Mitchell & Savill-Smith, 2004; Susi et al., 2007; Williamson, 2009). Instead, a few relevant assumptions are here brought forward, regarding why computer games hold educational potentials.

Computer games are described as a *persuasive* medium, with the capacity to influence gamers' thinking and actions (Williamson, 2009). It is argued that the way that computer games are designed and played "establishes sets of routines, rules and actions that the gamers need to learn in order to succeed" (p. 12). To successfully play a game, the gamers must figure out the rule system that constitutes the game (Bennerstedt, 2007). Gamers' actions therefore depend on the predefined game rules which form a framework for potential actions, and construct a *state machine* that responds to the gamers' actions (Juul, 2005). Consequently, a game persuades the gamers to carry out specific actions afforded within the game itself (Bogost, 2007), somewhat similar to "like listening to a persuasive argument" (Williamson, 2009, p. 12). From this point of view, computer games are recognised as having the power to influence people's thinking, and make them act upon situations in a particular way. Depending on the goal of the activity, this can be seen as an educational potential, and as having a positive influence on learning, but also as an obstacle.

Playing a computer game is further looked upon as a *situated practice* (Willamson, 2009). The idea of situated practice is based upon the belief that authentic contexts in which to situate learning are favourable learning environments (Dewey, 1899/1966; Lave & Wenger, 1991). Shaffer (2007) states that computers "let us work with *simulations* of the world around us" (p. 9). By creating dynamic representations of imaginary worlds, these simulations let us play with reality, and investigate complex systems that might be difficult to access in the real world. The assumption is that such dynamic representations – building on various modalities consisting of combinations of images, texts, symbols, interactions, sound etc. – provide a more authentic representation, in comparison to more traditional educational media (Gee, 2003; Shaffer, 2007). In line with these claims, but forty years earlier, Bruner (1966) argues that a game may constitute "an artificial but often powerful representation of reality" (p. 93).

Nevertheless, these ideas have been challenged by research demonstrating that the link between the representation and what it represents is not necessarily made by the gamer (Linderoth, 2004; Linderoth & Bennerstedt, 2009). The experience of playing a computer game is certainly a *real* experience, but the gamers do not automatically treat games as a representation of something outside of the game. Thus, the multimodal features of computer games should not automatically be taken as representations, but rather seen as material that potentially can *become* representations of real world systems.

Science education today

According to Roberts (2007), a number of socio-political factors have resulted in new external demands on science education. Notable factors include climate change, increased pace of globalisation, migration, emergence of new technologies, and information flow (digital media, computer game worlds, mobile technologies, social web applications etc.) Research indicates, however, that schools have great difficulties in meeting these demands.

It is a paradox that as science and technology are becoming more integrated into people's lives, their popularity as school and university subjects is decreasing (EC, 2005; Ideland & Malmberg, 2010; Linder et al., 2007). The tendency in most developed countries is that science along with technology and mathematics are the least popular school subjects among many students (Jidesjö & Oscarsson 2006; Lindahl, 2003; Linder et al., 2007; Osborne & Dillon, 2008). The ROSE study (Relevance of Science Education) is an international comparative project, aiming at investigating attitudes towards science and technology among 15-year-old students (Jidesjö & Oscarsson, 2006; Oscarsson et al., 2009). Results show that while Swedish students agree that the development of science is of great importance to our society, they generally perceive science subjects to be less engaging than other school subjects. Nor do they express any interest in going deeper into this field in future studies. One reason may be that the decontextualised content commonly presented in school science does not engage students' interest or commitment (Lyons, 2006).

It thus seems as if students have an interest for science when presented by other actors in society, but that they lose interest when these matters are brought into a school context and treated there (Lindahl, 2003; Osborne, 2007; Osborne et al., 2003). An explanation of the phenomenon may be an experienced lack of personal and social relevance, when science is taught as a school subject (Jidesjö & Oscarsson, 2006; Lindahl, 2003; Oscarsson et al., 2009). There is obviously a lack of correspondence between what students want to learn, and what is taught in the classroom (Oscarsson et al., 2009). Osborne states that "the problem with school science is that is gives uninteresting answers to questions never asked" (2008). In order to increase the interest for science subjects "[s]chool science needs to find a mechanism of presenting the major stories that science has to tell in a readily understood form" (Osborne, 2007, p. 109).

Socio-scientific issues and scientific inquiry

Research on science education has responded to this situation. One proposal, first advocated by the *Science, Technology and Society* (STS) movement, and later by the framework behind *Socio-scientific Issues* (SSI), advocates a contextualised view on science learning, and a stronger connection between course content and real world problems outside school (Aikenhead, 2006, 2007; Zeidler, 2007). The claim is made that science education would benefit from, and become more meaningful to the students, if the learning content were more connected to societal issues, and contextualised in authentic settings (Barab et al., 2007; Ekborg et al., 2009; Ideland & Malmberg, 2010). It is suggested that discussion about SSI's can provide a platform for more engaging experiences, because it involves "ill-structured problems, that is, problems whose solutions are multifaceted and undetermined" (Sadler, 2009, p. 11). As put forward by Kolstø (2001), investigation of SSI's "requires negotiation of scientific concepts, principles and practices in the context of open questions" (in Sandler, 2009, p. 11).

Central to the SSI ideas is that displacing the "to-be-learned" scientific content (concepts, and theories) from the situation where it has value undermines the educational goals that the school system aims at (Barab et al., 2007). It is also claimed that making "pure" scientific content the focal point might be conceptually and motivationally ineffective. The belief is that "rather than simply being told about these socio-scientific issues, students should engage in an inquiry process that situates the course content" (p. 59). That is, learning situations that support authentic learning, referred to as "learning which has a personal meaning and substance for the learner" (McFarlane, 1997, p. xi). To create such learning situations, many scholars advocate using decision-making processes, in which students are actively engaged, and take position in societal dilemmas (Davidsson, 2008). One way to achieve this is to engage students in *scientific inquiry* processes that situate the course content in societal concerns, and situations (Barab et al., 2007a). Scientific inquiry is here referred to as "the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Linn et al., 2004).

On the other hand, as pointed out by Barab et al. (2007a), and Jakobsson el al. (2009), the potentials of *situating* learning in contexts of use (Lave & Wenger, 1991) have been proven difficult to realise. Moreover, achieving knowledge of scientific concepts and theories is crucial to be able to enter the world of science, and thus to obtain an understanding of the *scientific formalism*, that is, the "formal structure and abstract principles that underline the conceptual framework of a content area" (Nathan, 2005, p 3). The dilemma for science education is to combine an understanding of the formal concepts and the structure of the scientific disciplines that are needed to understand and act in the world around us on the one hand, and on the other, to become engaged in the problems and alternate solutions to the problems encountered in this world.

Learning science through scientific practice

The ability to read and write science texts (including diagrams, drawings, symbols, charts, graphs, tables) is functionally viewed as tools for "doing science" (Norris & Phillips, 2003), or as stated by Lemke "learning science means learning to *talk* science" (Lemke, 1990, p. 1). That is, learning to use this specialised language of science, including the multimodal expression of scientific knowledge, in reading and writing, in reasoning and problem-solving, and in *practical* action.

According to Lemke (1990), we learn to talk science by talking to people who already master it, thereby acting as members in the community, the social practice that the world of science constitutes. In line with Lemke's ideas, Aitkin (2004) states that "scientific knowledge consists of both knowledge about a system and knowledge of *how to* investigate the system" (p. 248). This *how-to* knowledge cannot be gained solely or even primarily from reading about science, but must be gained by *practicing* science (Lemke, 1990).

Scientific practice, as referred to in this work, is understood to involve two dimensions[1]: (I) engagement in *scientific inquiry* processes, described as "the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Linn et al., 2004), and (II) usage and contextualisation (that is, the process of assigning meaning) of *scientific formalism*: *concepts* and *theories*.

When working with the design and research of a computer game environment for school science learning, Barab et al. (2007a) raise the question how to create learning contexts, through which scientific formalism can be experienced and practiced. How can we avoid "too much" situation, not enough formalism, or vice versa? One of the intrinsic challenges in creating such settings in school is "how to meaningfully relate experience, particular domain practices, and the accepted understanding of domain content, such that students develop an appreciation for the contextual value of the content while also beginning to identify the relevance of the underlying to-be-learned content when it is situated in other contexts" (p. 751). In other words, learning contexts where scientific concepts, theories and processes are used in practice, and at the same time promote and develop the understanding of scientific formalism.

Such learning situations are by Barab et al. (2007a) described as learning situations which "involves more than seeing a concept or even a context of use; it involves being in the context and recognizing the value of concepts as tools useful for understanding and solving problems central to the context in which one is embodied" (p. 751). It is further claimed that if the scientific content were embedded within a narrative context, it would help students to understand the value of concepts and tools that can be used for understanding and solving problems that appear in the context where the

[1] This definition is in accordance with formulations expressed in the Swedish syllabus for science education. Retrieved March 8, 2010, from www.skolverket.se

scientific content is embedded. By contrast, when such concepts and tools are presented in a decontextualised manner, students may have difficulties grasping their relevance, or investing them with personal meaning.

In line with Gee (2003), Barab et al. (2007a) propose that computer games have the potentials to "provide science educators with a new tool for establishing the legitimacy of science content, situating learners in rich narrative in which they adopt particular intentions and in which players' actions result in story changing consequences" (p. 752). These claims are also supported by findings presented in the review of empirical research included in this thesis (Svingby & Nilsson, Submitted).

Computer game play as scientific practice

Use of computer games developed according to the above principles might change the dominant educational processes, where experimentation has been confined to laboratories or classrooms, with weak connections to real world situations (OECD, 2003). Real world situations in this context are described as situations that "involve problems that can affect us as individuals (e.g. food and energy use) or as members of a local community (e.g. treatment of the water supply or siting of a power station) or as world citizens (e.g. global warming, diminution of biodiversity" (p. 139). To experience a sense of simulated "real" worlds is referred to as an understanding for intricate systems, and a sense of "how real world problems have complex causes and solutions whose properties-as-a-whole do not derive from the simple combination of constituent parts" (Barab et al., 2007, p. 64).

Squire and Jan (2007), and Aitkin (2004) highlight a number of game features, suggested to be especially relevant in relation to how computer games can provide science learning contexts. Central to their arguments is that the specific features of computer games have the potentials to afford simulated "real" world situations, where students can engage in scientific practice.

Firstly, Squire and Jan (2007) contend that computer games invite students to *inhabit roles*, which allow them to play with identities and move outside the traditional student role in the classroom, and into the role of an active participant stakeholder. Secondly, games provide students with *challenges* that are problem-based and gamer-defined, and that are meaningfully actualised in the game world. After performed action in the game world, the game reacts, provides feedback, as well as furnishing new problems to solve. These actions result in system changes that help the students to realise the goals, and the game world itself provides the students with a sense of intentionality and consequentiality. Thirdly, computer games can be thought of as *contested spaces*, where there is a spatially bound problem which is changed over time, depending on how the students move in the game space. Finally, games allow for the embedding of just-in-time *authentic resources* and tools that are critical to succeed during game play. These tools are situated, and required to proceed, solve problems and complete tasks. It therefore becomes meaningful to make use of them in relation to an adopted task, and not simply because described in a textbook, or a teacher claims they are useful.

Aitkin (2004) suggests that the following intrinsic qualities of computer games make them useful in facilitating science learning: "[t]he recreation of reality, the simulation of complex systems, visualisation and interactivity, engagement of the user in the practice of science, and construction and collaboration" (p. 244). Aitkin underlines that since computer games are able to *re-create reality*, students are allowed to investigate *complex systems* that normally lie beyond their reach by being too expensive, dangerous, or physically impossible to access. Also the *re-playability* of most computer games and the possibility to commit mistakes and start all over again are brought forward as important features. He also states that the *visualisation* and *interactivity* of computer games provide students with richer experiences, in comparison to more traditional educational media.

In line with Squire and Jan (2007), Aitkins (2004) argues that problems that are presented within computer games are genuine and "the process of solving them engages students in the practice of science (i.e. active exploration, discovery, theorising and experimentation), and the knowledge thus constructed transfers more easily to real-life contexts than does knowledge constructed through reading alone" (p. 210). It is claimed that computer games can assist the students in this practise, not only by concretising complex realities, but also by providing scientific tools (authentic resources) that are used "in the solution of scientific puzzles" (p. 248). The act of game play, referred to by Gee (2003) as a *reflective practice* in a four steps process, or by Aitkin (2004) as *puzzle-solving*, is claimed to be similar to the process of scientific practice, "involving cycles of action, observation, reflection and theorising" (p. 248).

Theoretical points – a summary

The theoretical perspective is summarised in number of points guiding this work.

I. Human action and learning are situated in the social and cultural interaction that we are exposed to through encounters with others, and with our surrounding environment. Actions are mediated and influenced by human and cultural products embedded in tools. This *dialectic* relationship between action and tools can only be understood by looking at it from different angles. To avoid the pitfalls of reductionism, *mediated action* is suggested as unit of analysis.

II. Mediated action is understood as a process involving the potentials of tools to shape actions, and how humans make use of these potentials in a particular situation. Almost all human actions are mediated, and thus not limited to physical, bodily actions, but also include speech and thoughts. A number of claims (put forward by Wertsch) concerning the characteristics of mediated actions and tools might be used as analytical tools when exploring computer game play in science education. In relation to the studies conducted in this work, some of these claims appear especially relevant: "(1) mediated action is characterized by an irreducible tension between agent and mediational means", "(3) mediated action typically has multiple simultaneous goals", "(5) mediational means constrain as well as enable action", "(6) new mediational means transform mediated actions", "(7) the relationship of agents towards mediational means can be characterized in terms of mastery", and "(8) the relationship of agents towards mediational means can be characterized in terms of appropriation".

III. The introduction of new technologies and mediating tools influences society on many different levels, including the educational system. The current post-industrialised educational system is at a stage of change that requires a new understanding of learning. Today computer game play is a culturally and socially significant activity among young people, and these experiences have changed the learning and teaching situation for schools.

IV. Science education is facing problems engaging students today. The SSI framework advocates a contextualised view on science learning. The belief is that authentic contexts in which learning can be situated constitute favourable learning environments. The claim is made that science education would benefit from, and become more meaningful to the students, if the learning content and activities were contextualised, and more connected to societal issues concerns. It is also suggested that to learn science, students should engage in scientific practice, including scientific inquiry processes situated in real world situations.

V. The intrinsic learning qualities of computer games are suggested to afford learning contexts where students can engage in scientific practice. Central to these arguments is that the specific features of computer games have the potentials to immerse the students in narrative contexts, and thereby situate learning and engagement in scientific practice in a context of use. That is, computer games are claimed to afford such science learning contexts by providing platforms for simulated "real" world situations. However, as pointed out earlier, we should be careful not to take for granted that computer game world are perceived by students as representations of such "real" world situations, since this might lead to false understandings of computer games as potential learning tools.

AIM AND RESEARCH QUESTIONS

Aim

The aim of this thesis is to explore actions mediated through computer game play in science learning contexts. This is investigated by studying gaming students in *action*, as well as students retrospectively *reflecting* on their actions. Conclusions drawn may add to the discussion of in what ways computer games can play a role in science education.

Research questions

What aspects of *scientific practice*[1] are:

- mediated through computer game play in a science learning context?
- used and referred to by students when reflecting upon their actions during computer game play in a science learning context?

The outcome of the four studies conducted (Nilsson & Jakobsson, Accepted; Nilsson & Svingby, 2009; Nilsson & Svingby, Accepted; Svingby & Nilsson, Submitted) along with the theoretical perspective presented in the previous chapter contribute to shed light on these overarching research questions. The specific research questions explored in each study are detailed in the forthcoming chapter *Summary of papers I-IV*.

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[1] As referred to in this work, understood as: (I) engagement in scientific inquiry processes, and (II) usage and contextualisation of scientific formalism, concepts and theories.

METHODOLOGY AND RESEARCH DESIGN

The following chapter discusses the choice of research design, based on the theoretical perspective that guides this work. A description of the research process is also provided, specifying how the studies relate to each other, along with a descriptive analysis of the two computer games played in the studies. Finally, details are presented, regarding the methods applied in gathering and analysing the data material. Ethical considerations, and procedures are described.

Methodological considerations

According to a socio-cultural view, learning is *not* looked upon as an isolated phenomenon occurring in the minds of individuals, but instead as something depending on interaction and collaboration with others, as well as the surroundings (Säljö, 2005; Wertsch, 1991, 1998). A methodological consequence of this is that actions and learning are analysed as an integrated component of participation in social practices. There is a *dialectic* relationship between action and tools, which can only be understood by looking at it from different angles (Burke, 1969; Wertsch, 1998). Burke (1969) has coined five terms referred to as pentadic elements, and it is here suggested that these be used as generating principles when analysing the relationship between tools and action.

In relation to studies comprised in this thesis, Burke's five terms can be constructed as follows:

Act: students collaboratively playing computer games, taking on the roles of journalist/medicine/veterinary students to solve a mystery (study I), and urban planners with the mission to create sustainable cities (study II, and study III).

Scene: science learning contexts in Swedish schools.

Agents: 89 students from six different compulsory schools in southern Sweden, grades 7–9 (aged 13–16).

Agency: the mobile educational game *Agent O* (Fergusson et al., 2006), and the commercial off-the-shelf (COTS) computer game *SimCity 4* (Maxis, 2003).

Purpose: to fulfil the goals of the given school assignments, as well as the goals of the computer games, with all that is implied with respect to exploring the game system, manipulating the underlying game mechanics, and further aspects involved in the act of computer game play.

To direct the analytical efforts towards one of these elements in isolation would be misleading (Burke, 1969; Wertsch, 1998). To avoid giving a simplified view on human action, Wertsch (1998) suggests an approach involving *mediated actions* as unit of analysis, perceived as a process involving the potentials of tools to shape actions, and how humans make use of these potentials in a particular situation (Wertsch, 1998). Thus, a *qualitative* research approach is assumed, seeking to illuminate, analyse, and understand situations in specific real world settings (Golafshani, 2003).

Besides these fundamental considerations, the choice of research design is determined by the objects that are studied (Ezzy, 2002). Since the unit of analysis is mediated actions that emerge during computer game play in science education, the three empirical studies were performed in school settings. In study I (Nilsson & Svingby, 2009), and study III (Nilsson & Svingby, Accepted), the gaming students were observed in action. In study II (Nilsson & Jakobsson, Accepted), the students reflected on their gaming actions in focus groups interviews initiated by the researchers. From a methodological point of view, the students and their actions should preferably have been studied during the process of the *ac-*

tual game play. This was not possible here for a number of practical reasons. However, since mediated actions are not limited to physical actions, but also include speech and thought (Wertsch, 1998), students' reflections are here perceived as mediated actions in the overall context, and analysed accordingly.

Research process

The process of conducting the studies supposed an *abductive* approach. This implies a research process that oscillates between theory, empirical data, and analysis, where the researcher observes, draws conclusions, and generalises, in order to create abstractions that make the observations comprehensible (Alveson & Sköldberg, 2006). The abductive approach is apparent in the sequential structure of the three studies. The research questions asked in study II were influenced by the experiences gained in study I, while study III is a follow-up to study II. In other words, gaps in theoretical and empirical understanding that became apparent during the research process were compensated in the subsequent study.

Another example of abductive reasoning in this work is how the theoretical assumptions on educational potentials of computer game play presented by previous researchers (Svingby & Nilsson, Submitted) served as background and source of inspiration, when identifying and formulating the research questions investigated. The claims presented in previous research were used to mirror, and put the conclusions drawn within this work in a wider perspective. However, they did *not* serve to form categories in the initial phase of the analyses. As emphasised by Ivarsson (2004), "when these descriptions are put to work as categories that are claimed to be characteristics of various technologies, they oversimplify and conceal much of the variations that can be found within each category" (p. 15). To avoid this, in the first two studies, categories that had not been pre-defined were applied in the analytical work. Nevertheless, in study III, the experiences gained in the preceding studies served as a background, both when planning the intervention, and deciding how to handle the data material gathered.

Research setting

The situations

Study I was the initial part in a larger design-based (Barab & Squire, 2004) project on mobile learning (Jönsson et al., 2009). The mobile game played in the study was designed, and implemented by the research team, and based on a platform for outdoor global positioning system (GPS) based augmented reality (AR) games developed by the MIT Teacher Education Program, in association with The Education Arcade (Fergusson et al., 2006; Klopfer & Squire, 2008; Squire & Klopfer, 2007). However, the subsequent directions taken by this larger project have not been followed up in the present thesis.

Study II, and study III were conducted in connection with Future City (Future City, 2008) which is a national, annual competition for Swedish students arranged by organisations within the building trade. The assignment that the students take on when entering the competition consists of creating sustainable cities for the future, by handling matters such as infrastructure, building constructions, transport system, power sources. According to the organisers, the aims of the competition are to: (1) create an interest for and knowledge about technology, science, engineering, and sustainable development; (2) increase the understanding of the complexity of urban planning as an activity that demands a great portion of creativity, problem-solving skills, team work, written and oral communication, and also to provide training within these areas of competences; and (3) be a forum for exchange between students, teachers, engineers and architects.

The participating students work in teams, consisting of fellow students, teachers and supporting mentors from the industry. The process is divided into three sequential components:

- to design and visualise a city by using the COTS computer game *SimCity 4* (Maxis, 2003),
- to build a physical model of a section of the city,
- to make a written and oral presentation of the city, clarifying the assumptions underlying their design choices.

Detailed guidelines for how to fulfil the given assignments are introduced to the student teams when they enter the competition. The student contributions, that is, the components mentioned above, are assessed by a jury according to clearly defined criteria, which also are presented to the student teams. The contributions selected by the jury are invited to a national final, where their contributions are presented to the public, further assessed and winners elected.

Future City has been running since 2004. In the school year 2007/08, when study II was conducted, approximately 1,000 students from 45 schools took part in the event. The following year, 2008/2009, when study III was conducted, approximately 2,000 students from more than 50 schools participated.

The informants

The population that this work focuses on is students in grades 7–9 (aged 13–16). The school involved in study I was a partner school of the research institution, and selected by the research team. The four schools involved in study II were chosen among participating schools from southern Sweden, with the aim of constituting a representative selection (Silverman, 2001) of the schools enrolled in Future City. The school involved in study III was chosen in collaboration with the Future City organisation. The participating students from each school were selected by the educators at the schools.

In total 89 students (35 girls, 54 boys) participated in the three studies. Since the participating student groups were selected by the involved educators without any specific instructions from the research team, the gender imbalance was accidental. The respondents in study I consisted of 17 students (9 girls, 8 boys) aged 15–16. Additionally, 11 students (9 girls, 2 boys) were involved in the process by filming the gaming student groups. Study II involved 42 students (12 girls, 30 boys) aged 14–15. Study III involved 30 students (14 girls, 16 boys) aged 13–15.

The computer games

Two different kinds of computer games were played in the three studies: *Agent O* (Alexandersson et al., 2005; Fergusson et al., 2006), and *SimCity 4* (Maxis, 2003). The following provides descriptions of the game mechanics (framework of rules) of the two games. The actual content, game elements, and narratives are further described in the papers presented in part II of this thesis, and will not be elaborated on further here.

Agent O

The students participating in study I played the research-based mobile educational computer game *Agent O*. The game is an augmented reality game that combines real world experiences with additional information supplied by handheld computers, and is played in an outdoor environment. It is inspired by the first and second generation augmented mobile educational games developed by MIT Teacher Education Program (Klopfer et al., 2005), and redesigned to suit Swedish school conditions. The game can be sorted into the genre *adventure* games, a genre which is driven by exploration and puzzle-solving. It is designed to be played in science and technology education, to enhance students' understanding of global interrelations in the area of sustainable development (Alexandersson et al., 2005; Fergusson et al., 2006).

Caillois' (1961) classic terminology regarding different kinds of game play, and gamers' involvements in these activities, consists of four categories: *agon* (games of competition), *alea* (games of chance), *mimicry* (games of simulation, and make-believe), and *ilinx* (games of vertigo). Applying Caillois' terminology, *Agent O* can be sorted into the agon and mimicry categories. It is a competitive activity, since success in the game depends on if students manage to solve the mystery presented. It was observed that competitive meta-gaming aspects arose between the student groups, since they were playing the game concurrently. *Agent O* is a *role-playing* game, offering the students the opportunity to assume certain roles, and play the game according to the chosen role, which is a type of activity belonging to the mimicry category. It is a *first-*

person role play, that is, the gamers do not manage their character in the third person; instead, they "are" the character.
According to Juul (2005), the rules of a game form a framework for potential actions and construct a *state machine* that responds to the gamers' actions. This state machine can be visualised by a "landscape of possibilities", or "a branching game tree of possibilities", that step by step are revealed. The first kind of game structures are referred to as *emergence games*, while the latter is termed *progression games*.

Agent O is a progression game, since new elements and features are introduced along the game play. The gaming process is goal-oriented (win and proceed, lose and remain). There is only one way to finish the game, and no way to go around the constraints by creating "own paths", or challenging the fixed route. The quests are serially presented, and have to be accomplished in a certain order. In contrast to emergence games, *Agent O* has a "set" story line, created by the game designer. Playing the game again would to all intents and purposes generate the same story, which therefore makes *Agent O* into a *complete-once game*.

Another set of expressions used to describe game systems is games of *perfect,* or *imperfect* information (Juul, 2005). Games of perfect information are games that the gamers have complete information about, from the start to the end. Examples are most card games, chess, and puzzle computer games. Games of imperfect information are games, where the gamers initially are not aware of what conflicts are going to emerge in the course of the game play. Instead, the game state is discovered along the way. Most computer games, both progression and emergence types, are games of imperfect information, including *Agent O* and *SimCity 4.*

SimCity 4

Like *Agent O*, *SimCity 4* belongs to the mimicry category. In some sense, it can also be sorted into the agon category, though the goal of the game is not directed by the game mechanics. Instead, the gamers themselves define their own goals, that is, what kind of city they what to build: a safe city, a big city, a sustainable city? *SimCity 4* is an emergence game, and can be described as an *open-ended simulation game*, also referred to as a "landscape of possibilities" (and limitations). The gamers take on the role of a mayor, but instead of playing the role in first persons, as in *Agent O*, they take the position of controlling the game on a large scale. The position or role of the gamers could be described as viewing and supervising the city from "above", managing its growth and progress. Games genres assuming this perspective are sometimes referred to as *management games*.

SimCity 4 is a game of imperfect information, since the rules that the gamers have to adapt to are discovered, experienced and learned about along the game play. In line with Juul's (2005) ideas, Zimmerman and Salen (2004) argue that the rules of a game limit player action, and to play a game is to learn how to handle these rules. In games of emergence, there are multiple solutions to problems, and the gamers are left with a range of affordances to act upon.

As in all kinds of cultural products, there are certain cultural values reflected in *SimCity* (Lauwaert, 2007). The question is what urban planning models and assumptions are embedded in the underlying game system of *SimCity*? Lauwaert (2007) brings fort three points of concern related to built in biases in the game mechanics: "(a) the fact that the game only offers zoned and thus sprawling urban development options to the player, (b) thereby excluding other visions on urban development (most notably those of New Urbanism), and (c) its tribute to the principles of California's *realpolitik* as practiced during the 1980s" (p. 197). *SimCity* "embeds very specific ideas about the American city", (p.197), viewed as a kind of "machine for commerce"; pragmatic, functional, and which grows according to material needs. Other types of cities; cosmic ("whose spatial layouts symbolically represented specific rules or beliefs"), or organic ("considered as a kind of organism: cohesive, balanced, indivisible") (p. 197) are not represented. Thus, to consider other kinds of more sustainable city types, where other human or ecological needs are given priority, is not possible.

Game	*Agent O*	*SimCity 4*
Genre	Research-based educational mobile game Augmented reality Adventure/mystery Role-playing First-person Complete-once	COTS game Open-ended Simulation Management
Play	Agon, mimicry Solve a mystery	Mimicry, agon Build a city
System	Progression Serial of quests Goal-oriented Imperfect information	Emergence Multiple solutions No explicit goals Goals set by gamers Imperfect information
Platform	Handhelds	PC

Table 1. A summary of the game descriptions.

Data and data collection

As mentioned above, a methodological consequence of the theoretical perspective guiding this work is that actions and learning are studied and analysed as situated in social practices. The aim has therefore been to find methods that focus on, and capture learning practices of a group, as well as the usage of tools in the context where they are applied.

According to the qualitative approach adopted, the research activity is seen as “a situated activity that locates the observer in the world. It consists of a set of interpretive, material practices that make the world visible”, and it is understood that “these practices transform the world” (Denzin & Lincoln, 2005, p. 3). Consequently, different practices used to generate empirical data present the world in different ways. A methodological anxiety pointed out by Marcus (1995) is the fact that different assumptions and expectations are embedded in the applied methods themselves. In order to get a nuanced picture of the subject studied, it is therefore advantageous to include multiple methods of data collection.

Methods applied

To increase the *reliability*, that is, the trustworthiness, rigour and quality (Goladshani, 2006) of the studies performed, various data gathering methods were applied.

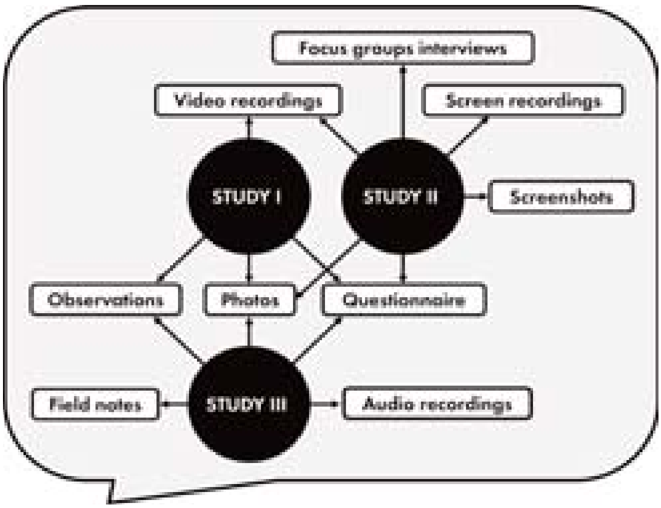

Figure 1. Overview of data gathering methods applied in the studies.

Video and audio recordings

The nature of the studies gave video and audio recordings an obvious advantage as data gathering methods. These recordings "provide researchers with a medium through which they can repeatedly inspect social activities in the context of their occurrence" (Heath & Luff, 1992, p. 10), and through that catch sight of occurrences that were not visible during live observation. The observers get a second chance to "come face-to-face with how talk organizes the world" (Denzin & Lincoln, 2005, p. 821).

As suggested by Lindwall (2008), video is a relevant tool to use in the kinds of "iterative, non-linear, and continuous nature of the analytical work" (p. 61) that also characterise the analyses performed in this thesis. To have the opportunity to replay the student actions, and repeatedly listen to their utterances, is also favourable to the abductive approach to the analytical work performed, implying a continuous development of research focus and questions. To use video and audio recordings also makes it possible to share the material with other researchers, and engage them in collaborative discussions about how to interpret the gathered data, which was an important part in the analytical phase of this work.

The manner in which the video and audio recordings were performed aimed at minimising disturbances caused by bringing in a camera or audio recorder into a school context. Nevertheless, the presence of the equipment as well as the researchers most likely had an effect on how the students acted, and what they were expressing. This has been referred to as the "observer's paradox" (Labov, 1972). This effect cannot be avoided, unless recordings of students are made in secret, which is not an option due to the ethical principles (see Swedish Research Council, 2002) that guide this work.

Observations and field notes

Study I and study III studied the gaming students "in the field", that is, observations were conducted in *naturalistic* settings. Naturalistic settings are referred to as situations where the researchers do not attempt to manipulate the setting, and study real world situations as they unfold (Patton, 2002). The field researchers can be referred to as "the research instrument" (p. 14), since by conducting observations and writing field notes, they play a central role in generating and analysing the data.

As stated by Patton (2002), observations can of course be made in *any* settings where people are doing things. The basic distinction between different observation strategies is to what extent the observers want to participate in the situation studied. Since the analytical focus of both study I and study III was actions emerging during the actual game play, the observation strategy applied was *participating observation* (Fangen & Nordli, 2005). The researchers strived to be perceived as passive participators, that is, to be present at the scene of action, but not actively participate. However, regardless of which strategy is adopted, "the observer affects what is observed" (Patton, 2002, p. 269), and the observer's paradox remains, which also became obvious in the studies. Inevitably, the situation is changed by the intrusion of the observer, depending on the nature of the observation, which is something that ought to be acknowledged and discussed.

Clearly, it is impossible to observe and take field notes of *everything* that happens in a situation. In order to keep the observation and field notes fairly focused and manageable, it has been suggested that the observer decides "what areas, objects, people, and events should be included in the observation" (Bailey, 2007, p. 94). There is no universal description of how field notes should be taken, since every setting requires different ways of proceeding (Patton, 2002). The chosen strategy in this work followed an observation guide, defining main targets of observation: collaborative patterns, decision-making strategies, and conversation topics. The guide was not regarded as a limiting framework of observations worthwhile documenting, but rather as an instrument intended to assist the researchers.

Focus groups interviews

Study II engaged the students in focus group interviews, which is a method that capitalises on communication between the participants in order to generate data (Morgan, 1997). Instead of the interviewer posing questions for each individual to answer, the participants are encouraged to talk to each other and discuss different experiences and views. The basic idea is that group processes can help the participants to elaborate on, and clarify views and reasoning that would be harder to access in an interview situation, where they would answer questions individually. The interactions between the participants in the focus group are also supposed to provide data quality control, since the respondents tend to "provide checks and balances on each other that weed out false or extreme views" (Patton, 2002, p. 336).

An interview guide was developed, to support the researchers during the focus groups interviews (see Appendix I). The idea of using an interview guide during the focus group interviews was to make the interviews more systematic and comprehensive by delimiting the issues explored in advance (Patton, 2002). The guide also ensured that that the same words and formulations were used when communicating with all of the eleven interviewed student groups.

Questionnaires
Questionnaires were used to gather basic background information about the informants, that is, age, gender, gaming experience, etc. The questionnaires were filled out by the students in direct connection to the research interventions.

Additional visual documentation
Besides using methods described above, Patton (2002) suggests that additional visual documentation can be supportive for the researchers when recapturing the research interventions. In the studies conducted, the physical settings and the participating students were photographed. Screen recordings, and screen shots documented the cities created by the students in the computer game.

Data gathering process

Study I
The study was conducted in naturalistic settings, and involved a single school class. It took place during an ordinary school day, both indoors in the classroom, and outdoors in the area behind the school, partly in the school yard. The session ran for 90 minutes, and was performed during a double-hour science lesson. After being introduced to the game and the game platform (the handhelds), the students were divided into groups of two to four students, allotted one of the three roles in the game, and then went outdoors to play the game.

The mobile game was played on a rather large area. After having discussed the alternative methods for gathering video data, the research team decided to let students document the gaming sessions. It turned out that the presence of the video filming student colleagues triggered an extra layer of actions, and provided a "scene" for the student to perform upon, which resulted in a somewhat different game play than expected.

Study II

The focus groups interviews involved eleven student groups at four different schools, and were conducted after the students had finalised their cities built in the computer game. The interviews took 20–30 minutes, and were performed at the schools. The researchers initiated the interviews by asking the students to demonstrate their cities. An interview guide was used to support to the researchers (Appendix I). A video projector screened the students' cities on the wall during the interviews.

Occasionally, the interviews took the form of an assessment, where students attempted to convince the researcher that they had produced a successful city. This was that was not the intention of the researchers, but possibly one of the side effects of being in the frame of a school discourse, where students take on the role of a student, while the researcher is given the role of a teacher.

The focus group interviews were video recorded. The video camera was placed in the back of the room on a tripod covering the conversations between the students, as well as the projected computer cities. Actions within the game world during the students' demonstrations of their cities were documented with a screen recording programme. On no occasion did any of the students comment on the fact that they were being recorded.

Study III

Study III was conducted in naturalistic settings at a school, and involved four gaming student groups. Each observation was accomplished in 90 minutes. The school had dedicated three weeks to playing *SimCity 4* as a part of their participation in Future City. The observations were conducted during the last week of this period, and for some of the groups during the last gaming session before the cities were to be handed in to the organisers.

During the observations, the researcher was sitting next to, or behind the gaming student groups, taking field notes, and sometimes asking questions when events appeared unclear. Audio recordings were used to capture students' conversations during the game play. The audio recorder was placed next to the computer screen, and the gaming sessions were recorded without any breaks or editing. On a few occasions, the students commented on the fact that they were being recorded, and picked up the audio recorder and played with it, using it as a microphone, singing a song, making jokes, etc.

Data material gathered

Study I: video recordings of the six gaming student groups (171 minutes), photographs, observations, and questionnaire answers.
Study II: video recordings of eleven focus group interviews (261 minutes), screen recordings (267 minutes), photographs, screenshots, and questionnaire answers.
Study III: audio recordings of the four gaming student groups (365 minutes), photographs, observations, field notes, and questionnaire answers.

Data analysis

The data material primarily used in the analyses was the video and audio data, combined with the field notes. The rest of the data served as background information, to get a richer view of the informants and the setting, as well as a memory support to the research team, when recapturing the research interventions.

Analytical attention

As previously stated, the unit of analysis treated is mediated actions that emerge during computer game play.

In study I, analytical attention was directed towards the gamers' concrete actions during the gaming session. The actions observed were thus actions directly connected to the actual game, but also actions that emerge in the situation as a whole; between the involved participants and the social practice that the game play took place within. For example, this included situations when students were "acting" in front of the camera, or bringing up irrelevant conversation topics (in respect to the game). Less attention was paid to the ways in which the students applied scientific formalism and knowledge during game play, since the research design did not generate empirical data which would have made it possible to make a comprehensive analysis of this kind.

That was instead the focus of study II, which aimed at investigating in what way a computer game can provide learning contexts for students to use and apply scientific concepts and theories when reflecting upon their cities. The analytical attention was directed towards situations where the students were involved in explaining, or describing scientific phenomena related to their cities, and where they used or applied scientific formalism in order to explain the assumptions underlying their design choices. Attention was also directed towards students' reflections upon what game strategies they used, and on constraints set by the game mechanics. In the subsequent study III, the analytical attention was directed towards similar aspects as in study II, but this time analysing data gathered from observing students during the actual game play. This focus was adopted in order to investigate if certain observations made in study II might also be valid when studying gaming students in action.

Transcription, categorisation and translation

The analytical work was conducted in an iterative process of going over the data material gathered, transcribing and re-transcribing it, finding coding system for categorisation, discussing and re-formulating tentative findings.

Different strategies to transcribe the data were used. In study I, all of the video data was transcribed in detail. Conversations were written down word by word, and time coded. Besides their conversations, students' actions were also included in the transcript, for example "reading aloud from the screen", "pointing towards other students", as well as occasions when the students were "acting" in front of the video camera. In retrospect, to transcribe all of the data in detail appears an excessively meticulous approach.

Bearing these experiences in mind, a different strategy for transcribing was used in study II. This time, the video data gathered was not transcribed in detail, but an overview of the actions was produced. Through discussions with the co-author, a selection of critical incidents related to the research questions were identified, and then transcribed in detail. In study III, yet another strategy for transcribing the data was used. The gathered audio data was listened through, and transcribed, not in detail word by word, but in form of a narration inspired by methods used in ethnographic research (Bailey, 2007). The field notes taken served as a basis for the narration produced. Besides describing the actual game play, the narration also contained descriptions of the setting, and background information on the participating students.

The transcriptions formed the basis for the next phase, namely to thoroughly study the text data produced "to notice and code systematically certain patterns in the conversations and activities of people depicted in the notes" (Berg, 2001, p. 76). Categories used to code data originated from the data material itself (bottom up) (Alvesson & Sköldberg, 2006), implying that the transcripts produced were analysed without any pre-defined categories. Instead they were scrutinised iteratively and reflexively in a two-phase analysis (Patton, 2002). The first phase resulted in categories for coding representing certain properties. The second phase of the analysis aimed at testing and verifying the patterns that were observed, and identifying possible sub-categories. The categories developed in each of the studies were used as analytical tool, to structure, interpret, and describe the findings.

To increase the reliability of the analyses performed, the data material were analysed by two independent coders, and the results of their analyses were compared. Whenever there were different interpretations, the data material was reanalysed, and the categories were successively modified in order to reach the final description. More detailed information about the properties of the categories and the coding system developed in the studies is found in the papers included in part II of this thesis.

All of the gathered data was in Swedish. The analyses were performed on the Swedish transcripts, and the excerpts that were included in the papers presenting the research results were translated into English after this analysis. As pointed out by other scholars, to translate naturally occurring talk is a difficult task (Linell & Persson Thunqvist, 2003), and the translations will not exactly correspond to the original meaning or form. To minimise mistranslations as much as possible, the excerpts selected were first translated by the authors (with Swedish as native language), and then checked by an English speaker.

Ethical considerations

The studies conducted within the framework of this thesis follow the ethical standards in research formulated by the Swedish Research Council (2002). The 89 informants were informed about the research projects before participating, and had freely accepted to participate. These procedures were managed by the teachers. In connection with the research interventions, the students were orally informed that their participation was voluntary, and that the gathered material (video, audio, photographs) would be used for research purposes only. Before the video camera or audio recorder was turned on, the researcher informed the students about the purpose of documenting, and that the material was not going to be shown to anyone outside this context. In none of the three studies did any student express any open dislike concerning the fact that they were being recorded. The student identities are hidden in the transcripts. Students who have appeared on pictures presented at seminars or similar occasions have approved the usage of these photographs. All the data material is stored in a secure place, and not used for other purposes than related to this work.

SUMMARY OF PAPERS I–IV

I) Gaming as actions: students playing a mobile educational computer game

The paper reports on students playing the research-based outdoor mobile educational computer game *Agent O*, developed to enhance students' understanding of global interrelations in the area of sustainable development.

The following research question was explored:

- What actions emerge in the interaction with, and are mediated by, the mobile educational computer game *Agent O*, when inserted in a formal school setting and collaboratively played there?

The analytic focus was on the gamers' concrete actions during the game play and on the social practice of the game play. The study was conducted in naturalistic settings during a double-hour science lesson. Students were engaged in two separate activities: playing the game, or documenting the gaming student groups. Seventeen students (9 girls, 8 boys, aged 15–16) in groups of 2–4 played. Additionally, 11 students (9 girls, 2 boys) in groups of 1–2 were documenting the activities.

Video recordings and observations were used to gather empirical data. The transcribed and analysed video data material consists of 171 minutes.

Results and conclusions

The outcome of the analysis is a description of eight more prominent actions and sub-actions that occurred in all student groups when playing *Agent O*. The eight actions are:

1) *Obtaining information/quests/instructions:* receiving information from the game or from other gamers, reading aloud, watching video sequences and other pictures, gathering and exchanging documents.
2) *Reasoning about the subject:* discussions about the subject, game content and how to solve the case.
3) *Role playing:* taking on the role assigned to students in the game.
4) *Discussing game technology:* talking about the technology, GPS, handheld computers, graphical interfaces, etc.
5) *Navigating:* deciding where to go, pointing out directions, referring to both the virtual and physical playground.
6) *Performing:* actions related to the presence of the video camera, such as over-acting, showing off, making fun, referring to what ought to be filmed.
7) *Moving:* between the different parts of the physical playground.
8) *Talking beside game matter:* bringing up and discussing issues irrelevant to the game.

These actions also interacted with each other, as well as generating new actions. In some cases they would reinforce other actions, while at other times other actions might be hindered or prevented. The combination of actions created a complex web, with layers of actions that carried the overall action forward. During the game play, the students constantly oscillated back and forth between the imagined game world, and their own reality. They were playing their allotted fictive role, while at the same time referring to their own personal experiences. By moving in and out of the various roles as student, gamer and performer in front of the documenting video camera, the students became a sort of a *student-gamer-performer-hybrid*, alternating between different roles, driven by different motivational forces.

The outcome of this study exemplifies the significance of the situation that a game is being played within, and that the educational use of computer games needs to be seen as interplay between game, student, context and educator. Findings suggest that the gaming actions here primarily worked as a source of motivation for the students, and less as a way to access educationally relevant content.

III) Simulating a "real" world or playing a game? Students playing a COTS game in the science classroom

and

II) Simulated sustainable societies: student' reflections on creating future cities in computer games

The papers report on two separate studies[1] exploring students' actions mediated when building models of sustainable cities in the COTS game *SimCity 4*. The activity was part of the students' participation in the competition Future City.

The research questions guiding both studies focused students':

- use of scientific concepts and theories,
- use of scientific processes,
- use of gaming strategies,
- reactions towards the constraints set by the game mechanics.

In study III, the gaming students were observed in action, whereas in study II students reflected in focus group interviews on their earlier actions during game play.

Study II involved 42 students (14 girls, 16 boys, aged 14–15) from four schools, who were divided in eleven groups. The interviews were video recorded, and students' interactions within the game world were documented with a screen recording programme. The transcribed and analysed video data material consists of: recorded interviews (261 minutes), and screen recordings (267 minutes).

[1] In time study II was conducted before study III.

Study III involved 30 students (14 girls, 16 boys, aged 13–15) divided into four groups. All participants came from the same school. The gaming activity was part of the students' self-managed project work, and only to a limited extent supervised by teachers. Field notes, audio recordings (365 minutes), and photography were used to gather data.

Results and conclusions

Study III

We assume that if gaming students apply a scientific approach to the dynamic system constituted by the game, any problem they encounter will be treated as part of the overall system, and related to the system as a whole. The analysis demonstrated that the gaming students were engaged in what can be described as "scientific practice", which means that they engaged in exploring, penetrating and manipulating the game mechanics, thus demonstrating understanding of the interdependency of factors in the system. This was, however, mostly done in a rather unsystematic way. Although students did observe and discuss the results of their actions and, as could be observed in later decisions, also learned from them, formal analyses or conclusions regarding game mechanics were largely lacking.

Besides dealing with the problems posed by the game structure as such, another question was if students made use of scientific concepts and theories when solving the problems that were presented in the game in terms of educationally relevant content. It was observed that while playing, students did not focus on scientific formalism, but on actually solving the problem of building a sustainable city, by acting upon the affordances offered within the rules framework of the game.

Since "immersiveness" is a fundamental characteristic of "good" games, the study was also directed towards observing to what extent students became immersed when playing. In what ways did the students critically comment on the internal premises, the constraints and biases built into the framework of the game? Students occasionally got engaged in the game, but they were not immersed into it. They treated the game play as part of the school task, and the game as a virtual dynamic system, rather than as a simulated "real" world. No attention was, for example, paid to the citizens, and how they would react if this was a real world situation. Students rarely related occurrences happening in the game world to situations in the real world. On the other hand, students were highly engaged. They tried out solutions, and criticised the game mechanics.

In spite of this, the gaming strategies used were tightly connected to the game mechanics that *SimCity 4* builds upon. To reach the goal of a sustainable future city, the groups chose various strategies, in most cases trying not to interfere with the game mechanics. The main discussion between students, thus, dealt with how to obtain balance *within* the game system.

The game obviously worked as a simulation context for urban planning, but with an inbuilt bias that was not accepted by the students. Both direct and indirect criticisms towards the game mechanics were expressed. Students also commented on the inbuilt value system, saying that the game only offers today's solutions, thereby preventing the building of a city for the future. This tension could potentially have been used by the teacher for reflection and discussion.

Study II

In study II, students were invited to reflect on the computer game play and the resulting cities. With respect to the use of scientific concepts and theories, the results demonstrate that the students were, to a considerable extent, able to explicitly explain how they had used and applied scientific concepts and theories during game play, sometimes using scientific concepts on the basis of a relevant scientific language, and sometimes using everyday words. However, some students were unable to use certain scientific concepts in a relevant and consistent way, and a number of misunderstandings concerning how to use or apply the involved concepts became explicit.

The analysis also showed that the students consciously considered and used various kinds of gaming strategies when choosing power supply systems, in order to attain the aim of a sustainable city proposal. Three major strategies were observed, indicating that the computer game created a situation in which students had to overcome complex obstacles in order to build a sustainable city. They had to articulate, discuss, and find solutions to environmental problems, where the game constraints contributed to preventing the students from using overly simplified solutions to complex issues. At the same time, however, the specific range of solutions enabled by the game would not necessarily have practical applications, since game premises simplified the issues in other ways.

The students expressed critical thoughts towards the game constraints set by the game mechanics. Some students also commented on the fact that the rules in the game are based upon certain American or Western value systems. Other students complained that the game world only offers today's solutions and designs, and that they found themselves restricted when it came to using their own creativity.

IV) Research review: empirical studies on computer game play in science education

A range of research reviews have been published regarding computer game play in relation to learning, and motivation to learn No review has been found focusing on the relations between computer game play and science learning. Thus, this research review focuses on empirical studies conducted on computer game play to enhance science learning, and positive attitudes towards science and science learning. Fifty publications published during the last decade that met the criteria were reviewed.

Results and conclusions

Almost all the games studied were developed by researchers. Some of the games were developed by teams of specialists. Such games mostly involved the students in a 3D world, inviting them to use a multitude of tools, to solve complex tasks over a substantial time period. The games focused more on enhancing general science inquiry skills, and less on developing the use of formal science concepts. On the whole, specific science concepts were less addressed by these studies, than the overall practice of inquiry. By contrast, some games focused the use of formal scientific concepts, aiming to demonstrate benefits of the games on concept learning. These games were mostly played by a single player, and did not offer possibilities for interaction between players.

Most of the studies report on positive learning results, but not always of positive attitudes to the game. The projects were on the whole theoretically well founded, with respect to science learning theory, game theory and design theory, primarily deriving from socio-cultural theories and theories of socio-scientific issues. Few studies report on research on COTS games.

Positive effects of computer game play in science learning were reported by 16 of the 19 studies assessing students learning. In seven studies, where results were compared with those of non-gaming students, the gaming students got better results, both on standardised and content-based tasks. Almost all studies report on the enjoyment and engagement in science learning that the games brought about. Of 15 studies assessing engagement, all but three reported of high levels of enjoyment and engagement during game play. On the whole, the studies reviewed indicate that educational games for science learning have the potential to favourably influence students' attitude towards science learning and, as a consequence, to accelerate students' learning.

DISCUSSION

The results presented in study I (Nilsson & Svingby, 2009), study II (Nilsson & Jakobsson, Accepted), and study III (Nilsson & Svingby, Accepted) are in this chapter related to the theoretical perspective guiding this work. The aim is to shed light on ways in which a socio-cultural view on human action might contribute to increase the understanding of learning potentials of computer game play in science education. Also discussed are the results regarding computer game play as mediated action in science learning contexts. The findings are further considered in relation to earlier studies, some of which are presented in the research review included in this thesis (Svingby & Nilsson, Submitted). Conclusions drawn here may thus add to the discussion on ways computer games can play a role in science education. Some concluding suggestions are also presented about implications for future research.

A central point of departure is the claim that the emergence of new technologies and mediating tools in society poses new challenges for teachers, as well as entailing other kinds of demands on the educational system (Becker, 2008; Linderoth, 2009a; Selander, 2008; Shaffer & Clinton, 2006; Sørensen et al., 2007). The generation of learners that has grown up in a media and communication landscape, formed by the introduction of new mediating tools, is calling for new forms of instructional designs (Jenkins, 2006a; Shaffer, 2007; Sørensen, 2009).

According to socio-cultural theory, the relationship between human action and mediating tools is essential in understanding learning processes (Säljö, 2005). Actions are mediated and influenced by human and cultural products embedded in tools, implying a *dialectic* relationship between action and tools: *mediated action* (Wertsch, 1998). Mediated action is understood as a process involving the potentials of tools to shape actions, and the use humans make of these potentials in a specific situation.

It is suggested that computer games have the potential to mediate actions by offering learning contexts where students can engage in scientific practice (Aitkin, 2004; Barab et al., 2007, 2007a; Squire & Jan, 2007). Central to the arguments is that the specific features of computer games have the potentials to immerse the students in narrative contexts, and thereby situate learning and engagement in scientific practice in a context of use (Barab et al., 2007a). In other words, assuming that authentic contexts are favourable learning environments, it is claimed that computer games afford science learning contexts, by providing platforms for simulated "real" world situations (Aitkin, 2004; Barab et al., 2007a; Shaffer, 2007; Williamson, 2009. The claim is further made that science education would benefit from, and become more meaningful to the students, if the learning context was more connected to societal issues (Aikenhead, 2006, 2007; Barab et al., 2007; Ideland & Malmberg, 2010).

To study computer game play as mediated action

In what ways can a socio-cultural view on human actions contribute to increase the understanding of the learning potentials of computer game play in science education? Wertsch (1998, p. 25) outlines a series of claims concerning certain characteristics of mediated actions and tools, which might be used as analytical instruments when studying computer game play in school learning contexts. In relation to the studies conducted in this work, some of these claims have received particular attention.

The first claim suggests that "mediated action is characterized by an irreducible tension between agent and mediational means" (claim 1). This statement becomes evident when viewing computer game play as an activity that changes, depending on how well the gamers actually master the computer game. Wertsch describes such processes by stating that "the relationship of agents towards mediational means can be characterized in terms of mastery" (claim 7). It was observed that the gaming students gradually increase their gaming competence during game play, and thus start to play the game differently, for example, by more consciously manipulating variables in the game system.

This means that the manner in which a session of collaborative game play in a school learning context develops will depend on ascending levels of gaming competences among the students. This can be related to Wertsch's claim, asserting that "the relationship of agents towards mediational means can be characterized in terms of appropriation" (claim 8). Another aspect also important to consider when studying collaborative computer game play – though *not* the focus area of this work – is how the students' individual gaming competences influence the power and authority structure between them, and ultimately affect their collaborative patterns. This can be linked to the claim "mediational means are associated with power and authority" (claim 10).

If we return to the claim "mediated action is characterized by an irreducible tension between agent and mediational means" (claim 1), the statement also highlights the importance of studying computer game play as activities that involve learning processes linked to the medium itself. This has profound implications for contemporary society. According to this view, the introduction of new mediating tools both influences *what* problems we can solve, and *how* the problems are handled. That is, our thoughts, and higher mental thinking are created and developed, depending on the tools we use, or have access to. As formulated by Wertsch, "new mediational means transform mediated actions" (claim 6), implying that new tools change the standards both for *what* is learnt, and *how* knowledge is acquired, thus putting new demands on the educational system.

Wertsch also emphasises the claim that "mediated action typically has multiple simultaneous goals" (claim 3), which is tightly related to Burke's (1969) pentadic element of purpose. In the studies comprised in the present thesis, it was clear that actions during game play served multiple purposes. On the one hand, these actions served to fulfil the goals of the given school assignments, while on the other, they also aimed at completing the goals of the computer games. This in turn, involved a number of other tasks, such as exploring the game system or manipulating the game mechanics.

Further on, Wertsch argues that "mediational means constrain as well as enable action" (claim 5). As stated in the previous chapter, the game mechanics of a game form a framework for potential actions to pursue. In the studies it was observed that actions during game play were tightly connected to the framework for potential actions determined by the game mechanics. In order to succeed in the game play, the students apparently had to adapt to the embedded game rules. Thus, attention needs to be paid to the issue of biases and cultural values embedded in the underlying game mechanics and how these influence actions, or induce certain gaming strategies applied by the students.

Actions mediated through computer game play in science education

Actions of scientific inquiry

In previous research it has been argued that computer games can afford learning contexts where students are supported in the practice of scientific inquiry and experimentation. This is achieved by providing scientific tools (authentic resources) that are used "in the solution of scientific puzzles" (Aitkin, 2004, p. 248; Barab et al., 2007a; Squire & Jan, 2007). The act of computer game play has been described as a *reflective practice*, where the gamer creates, tests, retests, and rethinks various hypotheses and solutions. Claims have even been made that the "puzzle-solving" characteristic of computer games is similar to the process of scientific inquiry, "involving cycles of action, observation, reflection and theorising" (Gee, 2003, p. 248).

Several studies on computer game play in science education (see Svingby & Nilsson, Submitted) demonstrate significant gains with respect to science inquiry skills (Nelson et al., 2005, 2007; Nelson & Ketelhut, 2007; Neulight et al., 2007). The results confirm the theoretical assumptions, that when designed in according to the criteria set forward in theories of educational game play, educational computer games do in fact immerse students in activities that help develop deep learning qualities, while practicing skills relevant to scientific inquiry. The question here is if the situations of game play studied in this work mediated this type of actions, and if so, which aspects of scientific practice became visible?

The outcome of study III, and to some extent study I, indicates that the gaming students were indeed engaged in scientific inquiry processes, in the sense described above. Throughout the game play, the students were engaged in exploring, penetrating and manipulating the game mechanics in an iterative process. For example, by planning ahead and setting the stage for "what was to come"; commenting on consequences; imagining future scenarios and taking actions as a preventive measure; going back and forth testing different solutions; gradually learning how factors in the game related to each other, and manipulating them to reach goals. Students further used their previous experiences as "experimental" data, in forming a "hypothesis" directing the sequence of actions needed to design a particular city.

The analysis thus demonstrates that the gaming students applied a complex set of reasoning and system thinking skills, including diagnosing problems, forming hypothesis, searching for information, demonstrating strategic thinking, debating with peers, and forming coherent arguments.

An aspect of scientific inquiry processes described by Linn et al. (2004), but which was not observed, was the process of "planning investigations", most probably since that was not a crucial action required in order to succeed in the game play.

When describing their game play in retrospective, the students in study II mentioned three strategies, that all involved central elements of scientific practice. One strategy consisted of implementing the most environmentally friendly alternative from the start, by choosing renewable sources of energy. This resulted in a slow industrial development, slow expansion of population, less income from taxes, and a low level of pollution. From a game perspective, this may be classified as a less successful strategy, even though it was successful from the viewpoint of building a sustainable society. Another strategy focused on implementing a more cost efficient, but less environmentally friendly power supply system, resulting in the generation of power at low costs, but with high levels of pollution. This strategy resulted in a quicker industrial development, and many citizens moving in. The initial use of power plants based on fossil fuels, in order to reach economic development, thus provided the basis for later large investments in more environmentally friendly alternatives.

Even though the two first strategies follow different kinds of logic and preferences regarding the importance of the economy, versus environmental sustainability, both demonstrate long term planning, strategic thinking, and an understanding of the complex game system. The students' actions during game play clearly had the characteristics of a reflective practice (Gee, 2003), and thus an activity that displays similarities to scientific inquiry processes, as defined by Linn et al. (2004).

A third strategy observed demonstrates that students explored weaknesses in the underlying game mechanics (referred to as *exploits*, Salen, 2008). This strategy increased the city budget, and was above all used to create possibilities to build environmentally friendly alternatives in the following step. In other words, the students aimed at fulfilling the school assignment, and exploited the games system to fulfil this goal. This was not achieved by applying scientific knowledge, but by using their gaming competence. Being able to apply this kind of strategy demonstrates high levels of gaming competence, and the ability to both understand and manipulate the game mechanics. Although these students did not demonstrate particular knowledge about environmental issues in the gaming situation, their strategy indicates high skills in system thinking, good understanding of a complex technical system, as well as knowledge of how manipulation of one part affects another part of the system.

Like the other two strategies found in this study, this strategy can also be described as a reflective practice, and a process where students created, tested, retested and rethought hypotheses and solutions. From an educational point of view, however, it should be noted that the strategy was disconnected from the scientific content embedded in the computer game. Students applying this strategy were not immersed in a narrative context with situated scientific matters, but in a complex system that they wanted to manipulate in order to accomplish the assignment. Despite these reserves, findings demonstrate that the game world in this case did provide a learning context for students to engage in some forms of scientific inquiry processes.

Usage and contextualisation of scientific formalism: concepts and theories

Previous research has put forward that computer games have the potential to provide learning contexts that situate learning and engagement in scientific formalism in a context of use (Barab et al., 2007a). The claim is that this would help students to understand the value of scientific concepts and theories.

The studies reported on in this work demonstrate that scientific concepts and theories were rarely used by the students during game play. This was obvious, both for students playing the COTS game *SimCity 4* (Maxis, 2003), a game that some of the students had previously played outside school, and for students playing *Agent O* (Fergusson et al., 2007), which they had never encountered before. To play the computer games was clearly associated with enjoyment outside of school, and not with school science and a serious learning situation. A possible conclusion is that students reacted in a situated way, implying that the educational meaning of the unusual situation of computer game play in a school setting was defined by their previous experiences of computer game play.

Earlier empirical studies have demonstrated similar effects. For example, Lim et al. (2006) reported on students' game play in an educational multi-user environment, as part of the science curriculum in a Singaporean school. Some of the students had refused to engage in the game, since they did not understand what the quest required of them. That is, the game was seen to be too far from the demands of the ordinary educational situation. On the other hand, the same study also demonstrates that other students were instead so immersed in the game play, that they actually lost focus on the learning task. In line with this, Wong et al. (2007) state that high level of immersion and interaction in game play can lead to distraction, instead of learning benefits.

Learning processes are intertwined with the surrounding culture, and constitute a situated practice that cannot be extracted from the context in which they occur (Lave & Wenger, 1991; Säljö, 2005). Computer games brought into a school setting are perceived as a cultural product, associated to expectations based on students' previous experiences of game play outside school. This implies that when situating computer games in a school setting, students' perception of game play as informal activity has to be taken in account. As put forward by Wyndhamn (1993) among others, the contextualisation of problems and assignments results in variations in interpretations, and how students deal with them. To solve a problem in computer game world as a part of an assignment in a school context, is handled differently compared to if the game was played outside school. Thus, playing computer games in an institutionalised setting is clearly a different activity, compared to playing computer games in times of leisure (Linderoth, 2009). According to a pilot study undertaken by Euström and Hofverberg (2007), it is very clear that students played *SimCity 4* differently in school as part of the science curriculum, compared to times of leisure. When playing for fun, students tried to maximise the income of the city council, and to build the biggest city possible, without bothering too much about environmentally friendly alternatives. In the school context, the latter was their prime goal.

Although observations were made of a wide range of actions emerging during the game play, separately or in conjunction with each other, the analysis of students' reasoning in study I indicates that they seldom discussed, or referred to scientific concepts or theories, in any of these situations. It appears that the students were fully occupied managing the situation, organising all the actions, role-playing, handling the game technology, navigating in the physical environment, moving, and so forth. It is possible that the number of actions that were handled left no room for deeper discussions regarding the scientific matters embedded in the game. This was instead elaborated on after the game play, and discussed once the students gathered in the classroom for group discussions initiated by the teacher.

Study III presents similar findings. The gaming students rarely referred to scientific concepts or theories during game play. If so, they used their everyday language to argue the pros or cons of specific moves. In case the students applied any scientific concept or theory, they did not elaborate the meaning of it, nor did they discuss it with peers. Their focus was directed towards solving the problem of building a sustainable city, and their design choices were guided more by the game mechanics and the affordances offered within the game, than by scientific knowledge.

As part of the curriculum, the goal set by the given assignment was explicitly to create a sustainable future city. Nevertheless, the gaming activities were for the most part not directed towards this goal in terms of modelling sustainability in the real world. Instead, the groups chose various indirect ways to reach the goal, not interfering with, or directly using the rules framework of the game to achieve their purpose. The main discussions between the students dealt with how to obtain balance within the game system. They were primarily playing a game, manipulating variables in a system, and not using the game world as a learning context to situate scientific concepts and theories in a context of use

By contrast, in study II, when students were actively asked to reflect on their game play, they were, to a considerable extent, able to explain how they had applied scientific concepts and theories during game play. They referred to scientific concepts, using both a relevant scientific language, and every day words. It also became evident when students were *not* able to apply scientific concepts and theories in a relevant and concise way, and their misunderstandings became explicit. The game world in this case provided a learning context where reflections on the embedded scientific content were facilitated, and made explicit.

The results of study II thus support the tentative conclusion that when computer games are used for specific science education purposes, a clear educational situation is needed (Egenfeldt-Nielsen, 2007; Becker, 2008; Facer et al., 2004). Studies on computer game play in science education have shown that lack of clear connection to the curriculum, or of follow up by the teacher in the class room, resulted in students not reaching the potentials for learning offered in connection with the game play (Nelson, 2005; Rehn et al., 2007). In line with the conclusions drawn in study II, previous studies demonstrate, however, that when computer game play is actively situated in a regular school situation and made part of it, students do bring forth, and make use of scientific concepts and theories (Barab et al., 2007, 2007a; Svingby & Jönsson, 2007). A study by Magnusson (2008) clearly demonstrates the importance of both the demand emanating from students to reflect on and formulate experiences of their game play, and mediating activities brought forward by the teacher, as a complement to the mediation of the game.

Such results suggest that students need to consciously relate the game play to a learning purpose. The results can be explained theoretically, from the assumption of actions as mediated by situations, and of learning as situated (Lave & Wenger, 1991; Wertsch, 1998). This line of reasoning is also closely related to the claims of computer games as platforms for *authentic* learning experiences (Aitkin, 2004, p. 248; Barab et al., 2007a; Squire & Jan, 2007; Williamson, 2009).

Supporting authentic experiences

Theoretically, to situate learning in *authentic* contexts has been seen as favourable for learning (Dewey, 1899/1966; Lave & Wenger, 1991). Authentic learning is described as "learning which has a personal meaning and substance for the learner" (McFarlane, 1997, p. xi). The question of authenticity is thus a central theme in research on computer games, research on learning research, and science education research (e.g. Lemke, 1990; OECD, 2003; Shaffer, 2007; Williamson, 2009).

Previous research suggests that computer game play is a highly experiential and situated process of learning, similar to the "the kinds of real-life contexts that are currently favoured among scholars of instructional design and methodology" (Becker, 2008, p. 122). Contexts provided in computer games also display features that can be related to the framework behind SSI (Aikenhead, 2006, 2007; Zeidler, 2007). Computer games are claimed to have the potentials to provide platforms simulating "real" world situations, and supporting authentic learning experiences (Aiktins, 2004; Barab et al., 2007a; Shaffer, 2007; Willamson, 2009).

There is no doubt that computer games *are* platforms for authentic experiences. During game play, the gamers inhabit roles, participate *in*, and *within* a system, and are forced to take the role of an active stakeholder (Gee, 2003; Squire & Jan, 2007). *Without* active participation, there can be *no* progression in the game play. As put forward by Squire and Jan (2007), computer games confront the gamers with challenges that are perceived as *real* problems – in the sense that they are personally experienced and emotionally invested by the gamer – and solved by employing tools afforded in the framework of the game. These tools are situated, and the context makes it meaningful for the gamer to make use of the tools provided in order to solve the problem, and proceed in the game. Thus, playing a computer game is a situated practice that situates problem-solving in a context of use that makes sense. Game play happens for *real* for the gamer, and is an authentic experience in that sense. It is less certain, however, if the embedded game content is actually perceived as a representation of what it is thought to represent (Linderoth, 2004; Linderoth & Bennerstedt, 2009).

In other words, the assumption that a game may constitute a powerful representation of reality in which students can investigate complex systems as representations of systems in “the real world” (Aiktin, 2004; Bruner, 1966; Gee, 2003; Squire & Jan, 2007) is only partly supported by the results presented in the work at hand. Students’ engagement was authentic and actually occurred, but on the other hand they did not relate to the game world as a simulated “real” world situation, but to as a virtual dynamic system for them to manipulate.

As observed in study III, the game played as part of the science curriculum did not seem to immerse students in the narrative, or to encourage them to directly relate to problems and social dilemmas encountered in the world outside the game world. Students did occasionally relate occurrences happening in the game worlds to situations they themselves had experienced, but their comments in most cases treated personal experiences, or anecdotes. The fact that students while playing did not use scientific formalism spontaneously is in line with other research results. The same pattern was for example reported from teacher students discussing socio-scientific issues in online learning environments (Malmberg, 2006; Johnsson, 2009).

On the other hand, students frequently criticised constraints set by the underlying games mechanics, based on value systems not in line with their ideas of a sustainable future, which suggests that they indirectly did reflect on how the model presented by the game related to actual conditions. For example, issues such as the relationship between tax income and welfare, criminality and numbers of police stations, structure of street systems and architecture. Finding themselves restricted in applying their creativity and knowledge during game play, students concluded that the game world only could support today's solutions and designs. Further on, as observed in study II, when students were asked to elaborate on their cities, they started to treat them as simulated "real" worlds, relating elements in the game to events in the world outside the game context. The educational situation thus mediated an interest, and engaged students in discussions of sustainability, and investigation in SSIs.

Providing constraints and illustrating complexities

The rules of a game obviously form a framework for potential actions, constraining the gamers' actions (Juul, 2005; Zimmerman & Salen, 2004). Depending on the nature of the game, different affordances are offered, that gamers may act upon when forming strategies, in order to become successful in the game play. When engaging in a game world, the gamer is subject to the rules of the game, and has to act according to them (Bennerstedt, 2007). This is why computer games are referred to as being a *persuasive* medium (Willamson, 2009), because they force the gamers to act upon a situation in a certain way.

In study II and III, a range of potential solutions was offered to the students playing *SimCity 4*, which is an open-ended simulations game, and a game of emergence. The game play can be described as navigating through a "landscape of possibilities" to choose between, but *not* without constraints. As underlined in previous chapter, a game is a cultural tool reflecting certain cultural values, just as any other cultural product (Lauwaert, 2007). As all technological tools, it has "an ideological bias, a proposition to construct the world as one thing rather than another" (Postman, 1992, p. 13). The internal logic of *SimCity 4* is shown to reaffirm "realpolitik as it was practiced in California during the eighties" (Lauwaert, 2007, p. 198) The original version of the game was developed during this period of time, and "these middle-class concerns were embedded in its program" (p. 2) which becomes apparent in the relationships between development, property taxes, crime and environment.

Students were given the assignment to build sustainable cities for the future. Sustainable development may be defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987), thus promoting integration of the three components: economic development, social development, and ecological perspectives (UN, 2005). To become successful *in the game world*, the students had to adapt to the embedded game rules, that is, the game designers' visions of successful urban planning. Since the logic of *SimCity 4* builds on growth and change, the goal to build a sustainable city would not be a rewarding gaming strategy, and might not be an easy undertaking on the whole. The findings demonstrate that students aiming at doing the "right" thing, by installing more environmental friendly alternatives, did not succeed very well in the game play.

The game played in study I, *Agent O*, belongs to a different game genre, being a game of progression, where information is revealed step by step in a serial procedure. There is only one way to proceed in the game, resulting in fewer variations between gaming strategies applied by the students. There is a set story line to follow, which always leads to the same ending. This rules set makes the game play into a search for the one and only *correct* answer, which actually makes it into a game with less similarities to complexities in a world outside the game context, compared to the game of emergence played in studies II and III.

In order to succeed in the game play, the students apparently had to adapt to the embedded game rules. That is, the students were persuaded by the game when it comes to taking certain actions within the frame of the game in order to become successful. However, their minds were seemingly *not* persuaded. This became concretely evident in study II and III. Even though all of the student groups appeared to be highly engaged in the game, they were not immersed into it. They expressed direct or indirect critical thoughts towards constraints set by the underlying game mechanics. The most profound critique was brought forward by the students in study II, since they were encouraged to actively reflect on the constraints.

The studies clearly demonstrate that the underlying game mechanics constrained students' actions, and confronted them with obstacles, just as circumstances encountered in the world outside the game world will also entail obstacles of various kinds. Even if the inbuilt biases in the underlying game mechanics are *far* from a representation of real world conditions, learning to deal with obstacles has a pedagogical potential, preventing students from using overly simplified solutions to complex issues. These embedded constraints set by the game mechanics may be seen as a simulation of complexities, illustrated by a student[1] explaining the process of building a sustainable city:

> "You start by building a small housing area which then begins to grow. You'll get to see how it evolves and develops a need for other stuff. It's pretty much that you have to organise, not only rescue services, you have to have a school, you have to have culture and museums and that kind of stuff too. It's a small picture of reality but it's still so much better than only to build a model, because then you wouldn't reflect upon all these things."[2]

Consequences for science education

Building on the potentials assumed by theory, and based on ideas behind the SSI framework (Aikenhead, 2006, 2007; Zeidler, 2007), researchers have developed educational computer games to support

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[1] The quote is not included in the paper (Nilsson & Jakobsson, Accepted), but a part of the data material analysed in study II.
[2] Translated from Swedish into English by the author.

the teaching and learning of science (e.g. Barab el al., 2007; Klopfer & Squire, 2008; Nelson & Ketelhut; 2007; Squire & Jan, 2007). These carefully designed educational computer games involve narratives describing societal problems that people and societies encounter. The problems focused have both scientific and social causes, demanding investigations and solutions that involve both dimensions. Research on such games reports that students were engaged and learning, but also points to problems, such as making students use embedded guidance (Nelson, 2005, 2007; Nelson & Ketelhut, 2008). The SSI approach to games appears to contribute to students' engagement in the game, as well as encouraging an interest in science. This seems to apply especially for students who normally are less interested in science, have low self efficacy in relation to science, and low performance (Ketelhut, 2006, 2007). The contextualisation of science learning, combined with a stronger connection between course content and problems outside school, appears to have supported these students.

The game *Agent O*, played in study I, was designed by researchers according to SSI principles. The game deals with issues of globalisation, in relation to sustainable development, with many entrances for discussions on social dilemmas. The study undertaken shows that when played in a school context, the game play did not elicit much discussion regarding scientific matters. When the students came back to the classroom, such actions emerged as a response to questions from the teacher. The games, thus, when used by the teacher, mediated some actions of relevance from a socio-scientific perspective. However, this was not achieved by the game alone, but required suitable initiatives from the teacher.

As brought forward in the research review (Svingby & Nilsson, Submitted), very few studies have explored how COTS games may be used as part of science education, building on the SSI framework. The outcome of study II and III, involving *SimCity 4*, indicate that this COTS game potentially could be used as a platform to situate scientific issues in an interesting social context. Even if the students during game play seldom were engaged in investigations or discussions using scientific formalism, the task of building a sustainable city, within the constraints of the game mechanics, forced them to encounter and solve problems in which social and scientific issues were dealt with. A dilemma arose between the restrictions set by the game mechanics – and which pushed the students towards solutions lacking social and environmental considerations – and the stated goal of the school assignment, that is, to build a sustainable city. Students were forced to discuss this dilemma, and/or to find solutions to it. Such solutions might mean exploiting the game system, or taking decisions that were seen as temporarily contrary to their goal of building a sustainable and socially responsible city, but which could in the long run be substituted for more responsible solutions.

The results from study II indicate that questions by the researcher led to student discussions of a socio-scientific character. For example, students reflected on how cars and industries in a certain area of their city caused high levels of pollution. They explained that their local production of carbon dioxide actually not only involved their city, but that it also may have a global effect, causing global warming. This led to reflections on the causal relationship between carbon dioxide and global warming. In fact, when students were asked to elaborate on their cities, they started to treat them as simulated "real" worlds, and related elements in the game to occurrences in the world outside the game context.

Students' insights concerning the restrictions imposed by the game mechanics may further be seen as an example of the competence of recognising and reasoning about complex relations, and seeing connections between economic interests, environmental issues, technical solutions and social welfare. For example, students explained that even if they were aware of the negative relationship between amount of cars, industry, air pollution and global warming, they did not choose to follow these insights when building their city. They explained that the game mechanics did not favour such thinking, since it builds on other preferences, such as economic growth. To become successful, they had to adapt to the *state* *machine* of the game, which formed a framework of potential actions for them to pursue. In other words, the game made them carry out specific actions afforded within the game world. The students expressed critical thoughts towards the constraints set by the game mechanics and which prevented them from choosing the solutions they wanted to implement. Such critical reflections on limitations set by the systems (in a game, or in the real world), may of course be used for learning, provided that teachers shape opportunities to discuss these issues.

As shown by the results presented here, if computer games are to be used in the classroom – not only for supporting authentic experiences, but also as a tool to establish the legitimacy of science content which can be related to societal concerns – then appropriate instructional actions are required. As also supported in previous research, the very nature of computer game play requires highly engaged and active students. However, "it is highly unlikely that we can automatically expect the computer games to facilitate a desired educational outcome, since this seldom is a part of the game universe or the game culture" (Egenfeldt-Nielsen, 2007, p. 8). Computer game play is an activity of great variation that can take many directions, and outcomes may therefore correspond to teachers' expectations in some cases, while leading to quite different outcomes in others.

Implications for future research

The thesis outlines a number of ways in which computer game play can play a role in science education. Computer games may provide platforms for engagement in scientific practice, support authentic experiences, and constructively constrain students' actions by confronting them with simulated complexities. The conclusions indicate that instruction is a crucial factor to benefit from these potentials of computer game play in educational settings.

As shown in the studies, the gaming students were primarily playing a game, not simulating a "real" world situation, or relating to occurrences outside the game world, unless they were specifically instructed to do so, as in study II. If the educational potentials of computer game play are to be reached, it is argued that teachers need to “transform the concrete experiences in computer games by building an appreciation of relevant elements, all while exploring these elements and linking them to other areas external to the game experience” (Egenfeldt-Nielsen, 2007, p. 9). Similar conclusions are also drawn in previous research, stating that the teachers play a significant role (Becker, 2008; Facer et al., 2004; Rieber & Noah, 2007). Still, several studies demonstrate that teachers seldom give instructions when computer games are played in the classroom (Sørensen, 2009).

On the other hand, the research review (Svingby & Nilsson, Submitted) showed that most of the studies reviewed actually did take an interest in the part played by the teachers. The kind of research-based educational computer games played in the studies were either games that afforded support, structure and help within the game itself, or games designed to be administered, controlled and supplemented by the educator. Still, the number of studies that have studied teachers’ involvement in a systematic way is so small that no extensive conclusions can be drawn. No studies explored teachers’ role when using COTS games in the classroom. It is therefore suggested in the research review that the role of the teacher is a promising area for further research. Both in this respect and others, there is clearly a need for more studies regarding models of instructional designs, to fully benefit from the educational potentials of computer game play in science education.

The research review also shows that the majority of the games reported on were research-based educational games. Surprisingly few studies have been conducted on the use of COTS games in science education, even though such games are reported as the type of games most often used in schools (Williamson, 2009), making the results presented in study II and study III rather unusual. This indicates a need for more research on how COTS games can be integrated into the science curriculum, taking advantage of the distinctive qualities of this kind of games. In relation to this, as also brought forward by Linderoth (2009), further research is required on which particular computer game genres and gaming activities might be relevant in relation to specific kinds of educational practices. A deeper study on the educational qualities of games genres building on different kinds of game mechanics would therefore be a valuable input for future educational use of computer games.

The research review also demonstrated that the majority of the studies reviewed were based on research interventions, where students spend relatively little time with the game. Eighteen (of 50) publications report on research interventions of only a few hours. It is obvious that the time of exposure to the game play intervention has an impact on what can be learned and experienced. This indicates a need for further studies of a longitudinal type, to follow learning processes of gaming students in a longer time perspective.

An important aspect to keep in mind is McLuhan's (1964) remark that since we are in the middle of this whole process of technological progression, and since it has become part of our everyday lives, it is difficult to distinguish its actual impact. To avoid producing unrealistic beliefs concerning the educational potentials of computer game play, research should continue exploring what happens *in situ* when computer games are brought in to school settings. As brought forward by Postman (1992), when exploring the use of technologies, attention should be paid to how the situation would look like *without* that particular technology. The research design of the studies conducted in this work unfortunately did not allow for this kind of comparison. Additionally, the research review demonstrates that only a small number of studies compared traditional classroom teaching versus use of the computer games, which implies a need for future studies, applying a methodology involving control groups, comparing the learning processes of non-gaming and gaming students.

Bearing these points in mind, a productive design for future research would possibly be a longitudinal study, involving experiment and control groups of students, playing various genres of computer games. Teachers would be involved in the research process, developing and evaluating models of instructional designs. Also students should preferably be actively engaged in the research process. Their presumably higher level of gaming competence would probably assist the researchers and teachers in not losing themselves in the abundance of promising opportunities, that computer game play, at first sight, seems to offer as an activity for learning and mediation.

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APPENDIX

Appendix I.

Interview guide used in the focus group interviews (Nilsson & Jakobsson, Accepted):

- Demonstrate your city, how did you plan and build your city, (power and water supply system, transport system, zones)?
- What section of the city did you chose to build a physical model of and why?
- How was the design work conducted? What determined your design choices?
- What are the similarities between reality and the game?
- Did you learn anything from playing the game?
- Do you consider your city to be a sustainable city?

[i] The computer games research literature (Svingby & Nilsson, Submitted) uses a wide range of expressions for games played using computer power, such as video games, console games, digital games, electronic games, interactive games, mobile games. For the sake of simplicity, in the present thesis the term *computer game* is applied as umbrella term for all kinds of games played on whatever digital platform.

[ii] Wertsch (1991, 1998) refers to tools as the *technical means* (e.g. computers, calculators), *artefacts* (e.g. books, computer games, scientific concepts or theories), and *signs* which are defined as psychological tools (e.g. language, symbols, formulas). He describes how our thoughts and actions are mediated by means of technical means, artefacts, and signs, stating that they are *mediating tools*, and mediators of actions. Computer games as mediating tools consist of combinations of technical means, artefacts and signs. In order to avoid confusion caused by too many expressions, *tools*, or *mediating tools*, will here be used as umbrella terms for all kinds of technical means, artefacts and signs.

PART II: PAPERS

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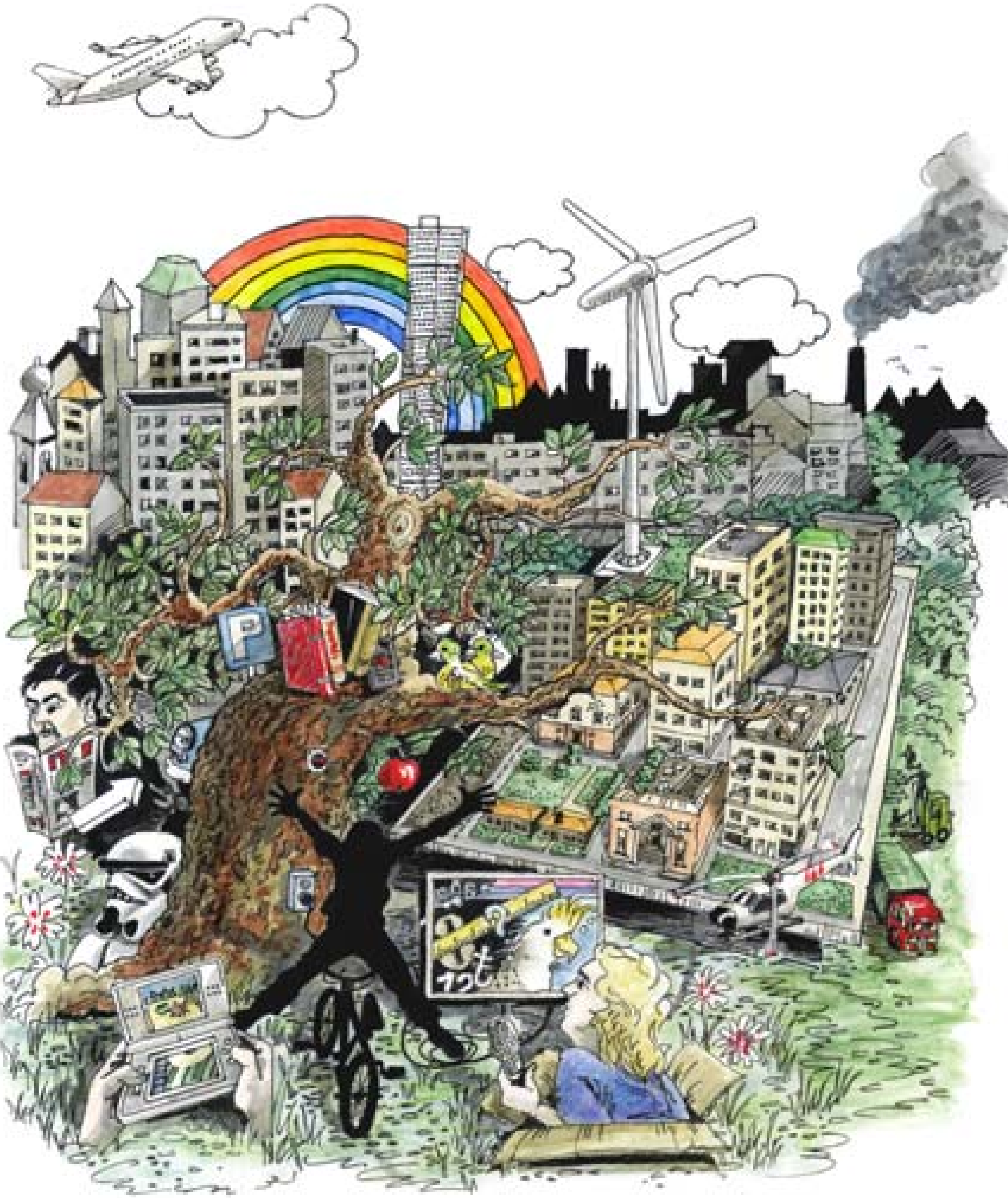

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