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Simulated Sustainable Societies: Students' Reflections on Creating Future Cities in Computer Games

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Abstract The empirical study, in this article, involved 42 students (ages 14–15), who used the urban simulation computer game SimCity 4 to create models of sustainable future cities. The aim was to explore in what ways the simulated "real" worlds provided by this game could be a potential facilitator for science learning contexts. The topic investigated is in what way interactions in this gaming environment, and reflections about these interactions, can form a context where the students deal with real world problems, and where they can contextualise and apply their scientific knowledge. Focus group interviews and video recordings were used to gather data on students' reflections on their cities, and on sustainable development. The findings indicate that SimCity 4 actually contributes to creating meaningful educational situations in science classrooms, and that computer games can constitute an important artefact that may facilitate contextualisation and make students' use of science concepts and theories more explicit.

Keywords Computer games · Mediation · Student reflections · Sustainable development · SimCity 4

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Introduction

Playing computer games, as well as participating in game cultures and in various kinds of social gaming networks, has gradually become a part of everyday life for many people in modern society (Mediappro 2006; Roberts et al. 2005; Swedish Media Council 2008). For example, in Sweden, nearly all of the of the boys (96%) and more than two-thirds of the girls (71%) in the ages 12–15 years play computer games (Swedish Media Council 2008). Computer games are not just played, "they are talked about, read about, fantasized about, cheated at, altered at, and become models for everyday life and for the formation of subjectivity and intersubjectivity" (Annetta 2008, p. 230). At the same time, Gee (2003) calls attention to the fact that in modern western countries, educational systems are desynchronised with technological developments in the rest of society. The educational potentials of computer games therefore risk to be overlooked or neglected. According to Gee, technological developments and the usage of new tools in society put special demands on the individual to learn or appropriate skills and competences needed to navigate in future societies. This development also implies that the standards both for what kind of knowledge is acquired, and the manner in which it is attained, are connected to the introduction of new technologies. Also, other scholars (e.g. Fromme 2003; Shaffer 2007; Säljö 2005) argue that the emergence of new tools and technology in society results in a new media and communication landscape that changes conditions for learning. Shaffer (2007), among others, argues that the new generation of learners who have grown up surrounded by interactive digital media, such as computer games, will become a serious challenge to traditional school settings. Indeed, we may already be witnessing these effects.

The educational potential of computer games has increasingly been a subject for discussion and research during the past few years. A number of overviews (e.g. De Aguliera and Méndiz 2003; De Freitas 2007; Egenfeldt-Nielsen 2006; Kirriemuir and McFarlan 2004; Mitchell and Savill-Smith 2004; Susi et al. 2007) describe educational advantages and disadvantages of such games when used in science education, as well as in other educational areas. Previous scholars argue that there is a need for empirical explorations of situations where students use computer games in different learning contexts, since computer games have developed to be artefacts of great importance in modern society and in different youth cultures (Kirriemuir and McFarlan 2004). It is argued that computer games constitute a context 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 multimodal; support early steps into a domain" (Dibley and Parish 2007, p. 35). Stapleton (2004) states that computer games contain intrinsic learning qualities, and could be regarded as providers of authentic, meaningful and powerful contexts for learning.

The last years of research activities on computer game play and learning have resulted in a growing body of projects presenting evidence-based results and conclusions, which argue for the educational usage of computer games (e.g. Barab and Dede 2007; Neulight et al. 2007; Squire and Jan 2007). Others (e.g. Annetta 2008; De Freitas 2007; Egenfeldt-Nielsen 2007; Wong et al. 2007) claim that empirical studies on learning effects of computer game play are relatively sparse, and that most of the research results presented so far are based upon theoretical assumptions. But, this does not imply that the educational use of computer games is unexplored, only that "research evidence is complex and thinly spread" (Kirriemuir and McFarlan 2004, p. 3). The study presented in this article is part of this emerging field of research, and aims at exploring the urban simulation computer game SimCity 4 (Maxis 2003), as a provider of simulated "real" worlds, and a potential facilitator for science learning contexts. The case studied is Future City,[1] a national competition for Swedish students (ages 12–15) who take on the role of urban planners, with the mission to create sustainable cities in SimCity 4. The topic investigated is in what ways interactions in gaming environments can support students' reflections on simulated "real" world problems, and how students contextualise and use their scientific knowledge in this learning environment.

[1] Future City web site: www.futurecity.nu (Accessed 2010-02-16).

Theoretical Background

Research on Computer Game Play in Relation to Science Education

Computer Game Play and Science Content Learning

Several studies indicate that computer game play in a science classroom context can support students' development of conceptual understanding of scientific phenomena and theories. For example Barab et al. (2007) conclude that students demonstrated a significant development of their understanding of science related issues when playing the computer game *Quest Atlantis*[2] as a part of their regular science training. The results indicate that the students increased their knowledge about water quality concepts, balancing scientific and socio-economic factors, and learned how to conduct a scientific inquiry. In the conclusion, the authors suggest that multi-user virtual game worlds support academic content learning, as they offer environments where scientific concepts are used in contextualised situations. Also, in the study by Neulight et al. (2007), the students displayed an increased scientific understanding after participating in a computer game about virtual infectious diseases. The study analysed how and in what way students developed their understanding when participating in computer game play in the online community *Whyville.net*.[3] The aim was to investigate students' understanding of virtual infectious diseases in relation to natural infectious diseases. The results reveal that the students' engagement in the game had an impact on their conceptual understanding of certain elements of causality involved in the spread and impact of infectious diseases. It was also shown that the experiences the students gained during the game play were later used to discuss natural diseases.

Steinkuehler and Chmiel (2006) report that computer games can contribute to a situation where the gamers become involved and engaged in scientific literacy practises in informal settings. When analysing text based forums in the multiplayer online role-playing game *World of Warcraft*,[4] they found a large number of situations where the gamers engaged in activities such as collecting data in the virtual world, creating new instruments to collect data, producing spreadsheets to analyse data, arguing about collection methods, and creating collaborative models of phenomena. According to the authors, this indicates that the gamers, to a high extent, use multiple modalities to

[2] Developed by Indiana University School of Education, atlantis.crlt.indiana.edu (Accessed 2010-02-16).

[3] Developed by Numedeon, Inc., whyville.net (Accessed 2010-02-16).

[4] Blizzard Entertainment Inc, www.worldofwarcraft.com (Accessed 2010-02-16).

make sense of their experience and produced new meanings with various media. Previous studies have also investigated in what ways computer games can provide dynamic representations of simulated "real" world situations, and how they can support or develop students' understanding of scientific investigations. According to Neulight et al. (2007), computer games can offer the students embodied experiences in complex domains that otherwise are difficult or impossible to access in ordinary science classrooms. It is also argued that dynamic representations—for example of graphics, motion, sounds and extreme short time phenomena (or long)—provide more authentic and explicit representations of what actually is being represented, than students would be able to observe for themselves in the classroom. This additional clarity consequently enhances students' learning processes.

Computer Game Play and Scientific Reasoning Skills

Several researchers contend that computer game play can promote and develop students' scientific reasoning skills. For example, Magnussen (2005) conducted a study of students' argumentation when playing a computer role-playing game called *Homocide*.[5] The aim of using the game in the science classroom in this particular case was to simulate an authentic situation, where the students should work as science experts. During the game play, the students took on the role of forensic experts with the mission to solve a series of murder cases. To solve a case, the students had to go through the process of forensic inquiry, which in many respects is similar to scientific inquiry. The research observations indicated that the game created an intense learning situation, where students themselves organised work in the groups, created tools for the investigation process and actively discussed problems, demonstrating peer-to-peer learning activities. Squire and Jan's (2007) study investigated students playing a computer game, *Mad City Mystery*,[6] in a formal classroom situation. It is concluded that computer game play can be a valuable pedagogical model for developing students' argumentation skills and increasing their general scientific literacy. According to Squire and Jan, this could be achieved by using game features (challenges, roles, places, collaboration, and competition) as resources for developing students' thinking about scientific argumentation. Throughout the game play, the students were required to develop narrative accounts of scientific phenomena, a process that compels them to develop their understanding and argue about scientific explanations. Finally, specific game features seemed to support the students' thinking processes, while at the same time enabling them to engage in meaningful and complex issues related to science.

Other studies have explored the ways gamers develop scientific reasoning skills in informal contexts. In the study by Steinkuehler and Chmiel (2006), text based, threaded discussions taking place in *World of Warcraft*[7] were analysed. They observed a positive development of the gamers' understanding of different scientific discursive practices. This was demonstrated by the gamers' collaborative knowledge construction, building on the ideas of others, and their use of counterarguments. Steinkuhler and Chmiel also observed different forms of model-based reasoning skills, such as understanding the systems and feedback mechanism. On the other hand, the researchers hardly discovered any progression with respect to the development of the participants' understanding of theory or their evidence-based argumentation in the discussions. In the light of such findings, Squire and Jan (2007) believe that the future challenges for science educators, as well as for computer game designers, are to develop pedagogical models to engage students in authentic forms of inquiry, where they can develop scientific thinking skills, gain knowledge about scientific methods, and learn how to conduct investigations. They feel that efforts should be directed towards helping students to think scientifically and use scientific arguments, in order to engage in contemporary issues with science content.

Computer Game Play in Educational Settings as a Motivational Component

One of the most commonly presented conclusions in previous studies seems to be that computer game play in educational settings can have positive motivational effects. Several studies demonstrate increased motivation and a strong sense of engagement among students when using computer games in science classrooms. Rosenbaum et al. (2007) report that motivational factors seem to be above all the "dynamic nature" of the computer games and that the students experience that their actions have an effect on the outcome of the game. Other studies have investigated the relationship between students' experiences of enjoyment when participating in computer game play and the learning outcomes. According to Hansmann et al. (2005), there seems to be a clear link between "having fun" while playing computer games, and a positive learning outcome. However, it is possible to questions this assumption, since several empirical studies (e.g. Rieber and Noah 2008; Sim et al.

[5] Developed by Learning Lab Denmark, www.lld.dk (Accessed 2010-02-16).

[6] Developed by University of Wisconsin, University of Wisconsin-Madison, www.wisc.edu (Accessed 2010-02-16).

[7] Blizzard Entertainment Inc (2004), www.worldofwarcraft.com. (Accessed 2010-02-16).

2006) describe difficulties in making the connection between enjoyment and learning outcomes explicit in research studies.

Some studies also call to attention that computer game play can actually lead to student distraction and lack of educational outcomes. For example, Lim et al. (2006) question the assumption that students' engagement in computer game play necessarily leads to engagement in the learning task embedded in the setting. In their study, they found that the computer game *Quest Atlantis* succeeded to serve as an intrinsic motivation factor, but that some students were so immersed in the game world that they lost focus on their school assignment. Also Wong et al. (2007) argue that the interactive nature of computer games sometimes seems to confuse and distract students, which may prevent them from focusing on the embedded scientific content.

Playing and Learning with SimCity

SimCity has already been explored in a number of prior studies dealing with learning and teaching with simulation computer games (e.g. Adams 1998; Gaber 2007; Lauwaert 2007). In particular, previous research pinpoints that students appear to be highly motivated by the use of SimCity in educational settings, because of its reality-like aspects (Gaber 2007). Summarising prior research results, Gaber brings forth two clearly identified cognitive learning objectives when using simulation computer games. The first is *holistic understanding*, which implies an ability to see that a situation is embedded in a larger context, and that the whole consists of many interconnected parts. Through such insights, the students develop *strategic knowledge*, and an understanding that their decisions may not only have a direct impact on the immediate situation, but also consequential impacts on other, indirectly linked situations. The second learning objective is *adaptive critical reasoning*, implying that when students are allowed to manipulate variables in a simulation computer game, they develop critical reasoning skills that may be used to solve problems. An example of such procedural learning can be when students identify a problem (e.g. effects caused by the level of carbon oxide in the atmosphere) and learn what type of actions they have to take to solve the problem.

Gaber (2007) also points out some severe limitations when using SimCity in educational contexts. He argues that the game is not a close approximation to reality, and that SimCity "exchanges people for aesthetics" (p. 116). The first limitation seems to refer to the fact that SimCity contains unrealistic assumptions. According to Gaber, there exists a serious gap between the game developers' assessment of reality, and the assumptions of professionals involved in urban planning. He also states that a city is never built from scratch, but involves cultural heritage and history. In SimCity, the game is based on unrealistic assumptions, for instance that urban planning is about economic development planning, and that the ultimate goals of constructing schools, hospitals, or parks are to promote economic development. This might send the wrong message to the student, and trivialise the major decisions dealt with during the gaming process. The second pedagogical limitation that has been identified with this game is the simplification of the citizens' aesthetics. In the city, citizens move around without interacting with each other.[8] The participants are never confronted with complicated social, economic, and cultural issues, and are left with building the city in a sterile environment. This can easily lead to conclusions that the issue of whether a city is a good or bad place to live in, essentially turns into an aesthetic question. A third limitation brought up by Lauwaert (2007), is the fact that SimCity "embeds very specific ideas about the American city: zoned (residential, commercial, and industrial areas are separated), sprawled, and practical" (p. 197), which excludes other ideas of cities that the students could simulate.

Computer Games as Meditational Means

On the basis of the short review of empirical studies presented above, it is possible to conclude that despite certain limitations, computer games indeed seem to have the potential to provide positive science learning contexts, both in formal and informal settings. But, what theoretical assumptions or theories about learning would constitute an explanatory model for the role of computer games in science learning contexts? How may we understand the ways in which computer games can contribute to support the development of students' conceptual understanding? In the following section, we intend to theoretically explore in what ways a sociocultural perspective on learning (e.g. Vygotsky 1978; Wertsch 1991, 2007; Säljö 2005) may contribute to increase our understanding about these issues. This, of course, does not imply that other approaches might not be equally fruitful.

A central idea in the sociocultural perspective is that learning processes and our thinking are based in the social and cultural interaction that we are exposed to, through encounters with others and our environment. Vygotsky (1978) argues that thoughts and higher mental functions are created and developed, depending on the mediating tools, artefacts and signs we use or have access to in this interaction. Wertsch (1991, 2007) defines *tools* as technical

[8] Simulating the interaction between citizens is not the purpose of SimCity. Instead, The Sims (Maxis 2000), which is an offshoot of SimCity, has a focus on simulated social interaction.

means (e.g. computers, graph calculators), which, together with the *artefacts* (e.g. books, computer games, scientific concepts or theories) in our surroundings, mediate and affect what and how we think. *Signs* are defined as psychological tools (e.g. language, symbols, formulas), that are used as means of thinking. He further describes how our thoughts are mediated by means of tools and signs, stating that *the mind goes beyond the skin* (Wertsch 1991, p. 33). This reasoning could be understood to signify that there exists a dialectic relationship between thoughts and tools, artefacts and signs. Thoughts are mediated and influenced by human and cultural products embedded in the tool, simultaneously as our understanding of how the tool or artefact may be used increases. These processes drive our thoughts and develop our learning. In line with this reasoning, Davidsson (2008) defines learning from this form of interaction as a successive appropriation of an artefacts' meditational potential.

Additionally, Wertsch (1991) argues that mediated action also is connected to mediational means. This implies that our actions are created and shaped, depending on what kind of mediation we experience, and the particular mediational means we use. He contends that the relation between the action and the mediational means is so fundamental that it would be more appropriate to talk about "individual(s)-acting-with-meditational-means" (p. 12), rather than just discussing individuals' action. Wertsch (2007) further differentiates between *explicit* and *implicit* mediation. Explicit mediation arises as a product of an intentional introduction of artefacts or signs in an ongoing activity. For example, this could be a learning situation where a computer game is intentionally introduced in order to facilitate mediation or enhance thinking about embedded science concepts. On the other hand, implicit mediation arises as a product of an unintentional use of already appropriated signs. Mediation cannot be taken for granted or seen as automatic. Kozulin (2003) argues that mediation must be grounded in *mediation of meaning*, since tools, artefacts and signs derive their meaning only from the cultural conventions that engender them. This means that educational situations need to focus on processes and meta-cognitive awareness about the science content embedded in the artefact, rather than only focus certain content.

Thus, when a sociocultural framework is used to understand how students develop new knowledge through participation in computer game play, it becomes necessary to focus on students' interactions with the game and to explore how the game influences their thoughts and actions in terms of mediation. A sociocultural framework also suggests the need to analyse the scientific concepts, theories and processes that are embedded in the game, as well as the ways and the extent to which the construction or design makes the meditational potential in the game explicit. Finally, this approach implies the need to study how the game is used in the specific educational situation. We will return to this discussion on the possible implications a sociocultural perspective may involve, when it comes to understanding the learning potentials of computer game play in a science education context.

Research on Students' Understanding of Sustainable Development and Global Warming

As mentioned in the introduction, the students in this study played SimCity 4 (Maxis 2003), to produce a proposal for a future sustainable city. In order to do this, among other things, they had to consider and make active choices concerning energy supply systems and consider what consequences these choices would bring. One important assumption in the present study is that when the students make choices and decisions about their proposal, they have to use and apply their scientific knowledge collaboratively, and in the process of communicating their ideas, they need to make their understanding explicit. This means that the students need to discuss the kinds of emissions different energy supply systems produce, the chemical content of fossil fuels, the carbon cycle, the relationship between carbon dioxide (or other greenhouse gases) and the greenhouse effect, the distinction between the depletion of the ozone layer and the greenhouse effect, as well as the causes of global warming. In the empirical part of this article, it is shown how the students focus on these issues when they reflect upon the discussions they have had, and on their choices and decisions concerning how to create their sustainable city. In order to make sense of the content of these reflections, and to analyse the students' statements, it is necessary to first consider earlier research results concerning how students understand these issues.

Several studies (Dove 1996; Jeffries et al. 2001; Andersson and Wallin 2000) conclude that students have difficulties explaining the greenhouse effect and global warming, and that they seem to mix up the natural greenhouse effect with the anthropogenic effect. A study by Boyes and Stanisstreet (1997) shows that a majority of the students investigated in their study had problems explaining the qualitative distinction between incoming solar radiation and outgoing heat radiation. Mason and Santi (1998) observe that almost half of the students (ages 14–15) in their study believe that it is the heat from the car engine that causes global warming. According to these studies, only a minority of students can describe that carbon dioxide is a greenhouse gas and explain in what way this gas has an impact on the global climate. Another common misunderstanding seems to be that students mix up the phenomenon of the greenhouse effect and the problem of the depletion of the ozone layer. According to Boyes and Stanisstreet (1997), a majority of the students in their study

(ages 14–15) express that "holes in the ozone layer" allow more energy from the sun to reach the Earth and thereby causes global warming. Boyes and Stanisstreet even state that more than half of the students in their study actually know that the increased level of carbon dioxide in the atmosphere causes global warming, but nearly all of them explain that this is because carbon dioxide is breaking down the ozone layer.

However, a more recent study by Jakobsson et al. (2009) questions some of the conclusions of these studies. Results in earlier studies may, to a large extent, be seen as consequences of the research methods deployed, in particular the use of written questionnaires. Following students' project work in school over a long period, Jakobsson et al. stress that many of the common misunderstandings reported in the literature do not appear in their investigation. It is argued that the appropriation and correct use of scientific language to discuss complex socioscientific issues is a gradual process. Students' understanding emerges in communicative practices, where they interact with others and with cultural tools in a focused activity. Nevertheless, their study still confirms that students struggle with a number of specific issues related to these complex phenomena. One of these issues is the difference between the natural and the anthropogenic greenhouse effect. Another conceptual problem is to understand what counts as a 'greenhouse gas', and how it should be understood in the context of the greenhouse effect. A third problem, for some of the students, is distinguishing between issues concerning the depletion of the ozone layer, and those related to the greenhouse effect.

The Study and Game Context

Aim and Research Questions

The present study takes its point of departure in the assumption that the emergence of new tools in society creates new conditions and strategies for learning, in formal as well as in informal settings. The next assumption is that computer games, and other digital media with interactive and visually driven learning environments, hold educational potentials in science education. It is argued that computer games and gaming contexts are characterised by intrinsic qualities that support learning, and are regarded as providers of authentic, meaningful and powerful contexts for learning (Stapleton 2004). Several studies (Barab et al. 2007; Magnussen 2005; Neulight et al. 2007; Price 2008; Squire and Jan 2007) also maintain that the use of computer games in science classrooms may result in students developing their conceptual understanding of scientific phenomena and theories. But in which manner do students perceive computer games as tools for learning and in what ways can students' reflections upon their computer game play help explicate science learning objectives?

In this study, the students are involved in a Swedish national competition[9] (see "Appendix 1"), where the urban simulation computer game SimCity 4 (Maxis 2003) is used as a context for the students to create a sustainable future city. The underlying aim of the study is to explore in what ways a computer game can provide simulated "real" worlds that are relevant for certain learning goals, and thereby become a potential facilitator for science learning contexts. The research questions are:

- In what ways do students use and apply scientific concepts and theories when reflecting upon their cities?
- What gaming strategies do the students use and what limitations and constraints do the students express when reflecting about the game environment?

Methodological Considerations and Analysis

The main aim of the methodological consideration in this study has been to find a research method that focuses on, and make it able to capture students' use and application of scientific concepts and theories when reflecting upon the their cities. This also includes reflections on their own gaming strategies and the limitations and constraints they experience during the game play. In order to come close to these questions, the participating students were given opportunities to consider and reflect upon their final city proposals, in immediate conjunction with the competition. In this situation, it was important that the students had access to their own city proposals, and thereby got the opportunity to build their reflections on their own cities. Since the intention was to explore the students' reflections and considerations, focus groups interviews were utilised to capture students' retrospective reflections of how they experienced and made use of the computer game, as well as their underlying assumptions. The process of building the cities was a collaborative task it thus felt natural to interview the students in the groups they had worked into create the proposals.

Focus group interviews as a data gathering method aims to capitalise 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 respondents answer

[9] Future City, www.futurecity.nu (Accessed 2009-04-03).

questions one by one. According to Patton (2002), the interactions between the participants in the focus group also enhance data quality, since the respondents tend to provide checks and balance on each other, weeding out false or extreme views. A weakness related to this method is that hierarchies within groups may affect which individuals are allowed to make their voices heard. The impact of the group dynamics might exclude some of the students from the discussion, and their thoughts on the matter might get lost. A focus group analysis that is true to its data ought to demonstrate the interaction between the participants, documenting group dynamics and the share of various group members. The selected excerpts, presented in the findings below, also aim to capture these interactions, since they can be understood as different or alternative ways to understand the specific situation. During the focus group interviews, the interviewers strived to ensure that all of the participants were offered opportunities to make their voice heard and to focus on the issues addressed by the research questions in this study.

Eleven semi-structured focus group interviews (2–6 students/group) with open-ended questions (see "Appendix 2: Interview guide") were conducted with 42 students (ages 14–15) from four ordinary Swedish compulsory schools. The respondents were randomly chosen among participants in the Future City competition from southern Sweden, to constitute a representative selection (Silverman 2001; Patton 2002) of the participating students and schools. All of the respondents had studied science subjects at lower secondary level for about one and a half year, and since the involved concepts and theories are part of the national syllabus at this level, it may be assumed that participants had at least basic knowledge about these concepts and theories before this study was conducted. This means, for example, that they had some experience of being taught at school about the concepts of photosynthesis, the carbon cycle, carbon oxides as products of combustion of fuels, the greenhouse effect, global warming, and greenhouse gases.

The interviews took about 20–30 min, and were performed at the schools. The interviewers initiated the interviews by asking the students to demonstrate their cities, explain the design of their city, and the assumptions that lay behind their design choices. In this situation, it was important that the interviewer adopted a passive attitude, to give the students an opportunity to speak freely without interruptions. A video projector was used to display the students' proposal of their cities on a screen during the interviews. The purpose was to offer the respondents possibilities to interact with their city proposal during the interviews, and to explain their thoughts behind different choices and decisions during the game. In order to capture the meaning of the students' utterances in a valid way and facilitate the analytic process, the students' interactions within the game environment were documented with a screen recording programme. This means that the total data material in the study consists of two parts, recorded on the same occasion: (1) eleven video recordings of the students reflecting on their cities (total 260:45 min), and (2) eleven screen recordings of students' interactions with their city proposal environment (267:05 min). Additionally, as a part of Future City competition, the students created physical models of their future cities. These were also analysed in order to get a richer description of the students' conceptual understanding of the involved concepts and theories.

The transcribed interviews were analysed without any pre-defined categories related to the research questions. Instead, the categories emerged through a two-phase analysis (Patton 2002). In the first phase of this process, Lemke's (1990, 1997) thematic patterns were used in order to discover patterns, themes and the meaning potentials in individual students' utterances and in dialogues between students. This also includes the interaction between the students and the game environment. In Lemke's terms, the specific thematic patterns are language patterns different from those that characterise everyday language or institutional discourses. Thematic patterns instead are observable as rhetorical structures, figures of speech, and other forms of accountable talk and action played out in classroom activities. In this study, the thematic patterns above all constitute the focus which the students chose in order to solve the assignment.

The second phase of the analysis aimed at testing and verifying the patterns that we observed in the material, and at identifying possible sub-categories. In this phase, all the identified and transcribed incidents from the first phase were thoroughly analysed, and possible explanation models addressing the research questions were made explicit. This implies that we primarily focused on situations, where the students were involved in explaining or describing scientific phenomena related to their cities, or situations where they used or applied science knowledge, in order to explain their choices or decisions. This part of the analysis also included students' reflections upon the gaming strategies and how they experienced game limitations and constraints. In order to increase the reliability of the study, the data 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. This means, for example, when the coders initially had different perceptions of the students' gaming strategies they returned to the data material to compare the reliability of the different interpretations.

Findings

Students' Understanding of Scientific Concepts and Their Underlying Reasoning was Made Explicit in the Dialogues

One important aim in this study is to analyse and describe in what ways students use and apply scientific concepts and theories when they reflect upon the concept of a sustainable city. This means that the aim is to describe to what extent the students are able to use their scientific knowledge, when explaining the decisions and choices they made in the process of creating their cities. The analysis revealed that the students, to a considerable extent, were able to explicitly explain how they had used and applied the scientific concepts and theories. At the same time, the analysis also showed that the students sometimes used scientific concepts on the basis of a relevant scientific language, and sometimes used everyday words. It furthermore became obvious that some students were unable to use certain scientific concepts in a relevant and concise way, such as, "photosynthesis", "carbon dioxide" and "greenhouse gases". This indicates that several misunderstandings concerning how to use or apply the involved concepts became explicit. On the other hand, a number of students were able to use these terms in an adequate way. This is exemplified in Excerpt A, where Bobbie and Andi are explaining what the air pollution consists of, and what problems are related to this phenomenon.

Excerpt A

TURN	TIME	STUDENT	EXCERPT
161	06:10	Bobbie	The air pollution is just right there over the dirty industries. ((pointing out the polluted areas in the city))
162	06:16	Interviewer	What kind of air pollution is that?
163	06:17	Bobbie	Well, they're from, well, it is from the dirty industries and then there are exhaust fumes from the cars too, I think
164	06:25	Andi	I think they are estimating that. (2.0) You can read here that we don't have as much over there

Excerpt A continued

TURN	TIME	STUDENT	EXCERPT
165	06:31	Bobbie	No, I don't think we have anything at all over there. (6.0)
166	06:38	Andi	We have a bit, as you can see, that is located here as well
167	06:43	Bobbie	You can see here that it's, this road there, you can see that is has been taking a lot of pollutions there ((inaudible)) and then you see how many cars they have
168	06:55	Interviewer	What's that, what is it in the cars' exhaust fumes that might cause problems?
169	06:59	Bobbie	Well, it's the carbon dioxide and nitrogen oxides
170	07:02	Andi	And then some nitrogen too
171	07:05	Interviewer	In what way can carbon dioxide be a problem?
172	07:09	Bobbie	It causes global warming
173	07:12	Interviewer	How is that linked to this city, so to say?
174	07:15	Bobbie	[Well, it is]
175	07:15	Andi	[To] this city it will probably turn out that the carbon dioxide that is produced here, it will, well it will, it will kind of place itself here, kind of in the city in a way that it is kind of located here. But at the same time, the actual effect of it might not even be visible in our city. (2.0)
176	07:38	Bobbie	But, one could say, in general, that it will be like in the rest of the world, it will become warmer
177	07:44	Interviewer	Mm, how does that work then? How is that linked to the carbon dioxide and the global warming?
178	07:48	Andi	Well, I don't exactly remember the chemical but, yes, I've forgot it but [it]
179	07:57	Bobbie	[Carbon dioxide] is one of the greenhouse gases

Excerpt A continued

TURN	TIME	STUDENT	EXCERPT
180	08:00	Andi	It absorbs, it causes that the Earth absorbs more heat and (.) creates a kind of an evil circle with more and more carbon dioxide. And if we don't put an end to that, because I mean, the ice is melting and it doesn't reflect as much heat away from Earth anymore. So, I mean, some carbon dioxide here ((referring to the city)) means pretty much, but at the same time, to be a big city so it this anyway relatively good. Because in this game you cannot do so much about air pollution. We can't, we can't kind of build trees and such, because it doesn't affect, and we have to have industries otherwise the city will not evolve

The excerpt takes its starting point in Bobbie's statement (turn 161) that the air pollution is above all related to the areas with *dirty industries* in the city. When the interviewer asks what kind of pollution he is referring to, he clarifies this statement by adding that *exhaust fumes from cars* (163) also contribute to the city pollution. Further on, he reinforces this statement by claiming that exhausts from cars cause *a lot of pollution* (167) in separate parts of the city, which are concentrated to specific roads. So far, the dialogue between the students seems to touch the matter of pollution in the city on a general level, and with everyday use of the language. But when the interviewer asks what in the exhausts might cause problems (168), Bobbie immediately changes the language use to a scientific discourse, explaining that it consists of *carbon dioxide and nitrogen oxides* (169). This indicates that he can use the scientific terms for the gases as resources for explaining the main content of car exhausts in a relevant way, and that he is able to use the terms in order to argue that these gases can cause environmental problems in the city. He also makes a decisive distinction by mentioning carbon dioxide in the singular and nitrogen oxides in the plural. He thereby clarifies that he is aware that there exist several nitrogen oxide gases in car exhausts. At the same time, Andi mentions nitrogen as an important component of the gases (170).

Further on, when the interviewer focuses on in which ways carbon dioxide can be a problem (171) and how this relates to their city (173), Bobbie at once relates the question to the phenomenon of global warming (172). Also, Andi argues that the local production of carbon dioxide will have a global effect, suggesting that *the actual effect of it might not even be visible in our city* (175). By that he seems to argue that the problems related to carbon dioxide actually not only involve their city, but also have a global effect. Bobbie clarifies this reasoning further on, by stating *it will be like in the rest of the world, it will become warmer* (176). This short passage of interaction between the students and the interviewer indicates that the students are able to link the combustion of fossil fuels, in the form of car exhausts, with the phenomenon of global warming. In order to do this, they have to understand that cars exhausts consist of carbon dioxide, that this gas is a greenhouse gas, that greenhouse gases might have an effect on the global temperature, and that the phenomenon of global warming can constitute a threat to their sustainable city. This interpretation is reinforced, further on, when the students, on request of the interviewer (177), try to sort out in what ways an increased global temperature is linked to carbon dioxide. Bobbie makes this link explicit, by arguing that *carbon dioxide is one of the greenhouse gases* (179) and Andi collaboratively supports this statement, by filling in that *it absorbs, it causes that the Earth absorbs more heat* (180). Furthermore, he makes his understanding of the causal relationship explicit, by expressing that humanity has *to put an end to* (180) *the evil circle* of too much carbon dioxide in the atmosphere and by relating this development to the melting of the ices in the world. It is also clear that he is aware of the global effects of local exhausts of carbon dioxide, by expressing that *some carbon dioxide here means pretty much* (180) and relating this statement to their city. At the end of his reasoning, he additionally makes a reflection upon the limitations of the game, showing that they are aware of the positive effect of planting trees, but that this did not affect the game at all.

In the second excerpt, Lori, Kavi, and the interviewer are involved in a discussion about their city proposal. The analysis of the dialogue between the students makes it clear that they express an alternative way of interpreting the concept of a "sustainable city", compared to the students in the first excerpt. At the same time, the analysis of the dialogue makes some possible misunderstanding of the scientific concepts explicit.

Excerpt B

571	07:11	Lori	We have a lot of trees and similar, lots of parks and things worth seeing
572	07:15	Interviewer	There is a lot of green zones. This city is a little bit different from some of the other cities which are very crowded with a lot of houses everywhere
573	07:24	Kavi	Look, the environment and health scale is close to max ((showing the data charts))
574	07:25	Interviewer	Yes, why is that?
575	07:26	Kavi	A lot of green
576	07:29	Lori	Yes, that it is not so squeezed together, but like a little bit more scattered
577	07:33	Kavi	There are lots of things to do, many things to look at
578	07:37	Lori	Yes, we have a point, not to squeeze the city together, but to give it some air, so to say, (.) some space
579	07:48	Interviewer	Why a lot of green areas? Can you read it somewhere in the game or where do you get that from?
580	07:52	Lori	[No]
581	07:52	Kavi	[It] cleans the air, absorbs the nitrogen, or whatever it is
582	08:02	Lori	Instead of having a huge city where everything is just squeezed in, we have spread things out a bit. It's nicer, it is good
583	08:10	Kavi	The people will be happier too
584	08:14	Lori	Yes, because everybody doesn't want to live in a big city, I think. It is, a lot of noise and such things. (.) This is a big city that has spread out
585	08:25	Kavi	The pace is slower

Lori starts the conversation by explaining some underlying ideas behind their city, pointing out that they *have a lot of trees* (…) *parks and things worth seeing* (571) in their city. By that she seems to express a will to draw attention to the fact that a fundamental condition for their city has been to plan a lot of green areas. Kavi supports this statement, by arguing that they actually have been successful in fulfilling this goal, since the data charts in the game clearly indicate that *the environment and heath scale is close max* (573). When the interviewer asks how this is possible, she clearly relates this to the existence of a *lot of green* (575) areas in their city proposal. A possible interpretation of the dialogue so far is that the students primarily focus the task of creating a sustainable city in the computer game environment according to the embedded game rules. This interpretation is reinforced in Kavi's statement, where she focuses the importance of the environment and health scale in the game. It is also obvious that the students want to argue for the existence of green areas in their city from an aesthetic and recreational perspective, by stating that the green areas are *things worth seeing* (571) and by claiming that *there are a lot of things to do, many things to look at* (577). This is reinforced by Kavi's statement that *the people will be happier too* (583). All these statements indicate that Kavi and Lori above all focus on the fact that they have tried to create prerequisites for the residents to live in a city with a sustainable lifestyle.

However, when the interviewer, more explicitly, asks why they have planned a lot of green areas in their city, Kavi immediately refers to the notion that these areas *clean(s) the air* (581). On the other hand, she argues that this is due to the fact that the green areas *absorb(s) the nitrogen* (581). Lori does not question or contradict this statement. Kavi's statement could lead us to believe that she expresses a misunderstanding of photosynthesis, and how this concept may be used in order to clarify in what way green areas *clean the air.* Actually, it is not possible to draw the conclusion that Kavi does not understand the concept of photosynthesis, strictly speaking, but it may be argued that she is not able to use or apply it in this specific situation. On the other hand, it is possible to say that she expresses some hesitations about her own statement, as she adds *or whatever it is* (581), which may indicate an uncertainty about whether she might be using the wrong term.

The two excerpts presented above constitute examples where students, retrospectively, reflect upon their proposals for a sustainable city produced in SimCity 4 (Figs. 1, 2). We will argue that situations like these may create possibilities to make students' use and application of the embedded scientific concept and theories explicit. This means that the students' abilities to use and apply their knowledge and their understanding or misunderstanding of the concepts or theories become visible. In the total empirical material, it has become obvious that some students displayed a misunderstanding of the role of carbon dioxide as a link between the combustion of fossil fuel, and global warming, or were unable to use this knowledge to solve problems related to their cities. These problems of comprehension and/or application of central scientific

Fig. 1 Data view indicating level of air pollution in the city

Fig. 2 An example of a city created by the students. (© Electronic Arts Inc. 2003)

concepts are, to some extent, confirmed in earlier studies (e.g. Dove 1996; Jeffries et al. 2001; Jakobsson et al. 2009). Additionally, some students seem to confuse the greenhouse effect with the depletion of the ozone layer, or expressed other possible misunderstandings related to the phenomenon of global warming. Similar problems are described in science education literature (e.g. Boyes and Stanisstreet 1997; Jakobsson et al. 2009).

However, our point here is not to highlight all the possible mistakes or misunderstandings that students can express, but rather to discuss possible roles computer games could play in science classrooms. The results from our study indicate that computer games can contribute as a facilitator and an artefact for making students' understandings and abilities explicit and visible. We will return to this discussion, but first we will explore the students' reflections on their game strategies and their ideas on the game's limitations and constraints.

Students' Reflections on Gaming Strategies

One important issue the students had to consider during the game play was to decide what kind of power supply systems they chose to install in their cities, and what consequences their decision would have. In SimCity 4, a variety of alternatives are offered, embedded in the game. These are more or less environmentally friendly, and present different degrees of cost efficiency. The analysis of students' statements reveals that the relationship between costs, amount of power generated, and environmental impact functioned as distinct steering factors in their choice of power supply systems. Most students also referred to game-specific requirements, such as the size of population and the percentage of high-tech employments, that had to be fulfilled before the most advantageous power plants could be installed in the city. In Excerpt C, Andi and Bobbie reflect upon their decisions related to some of these issues.

Excerpt C

102	000:48	Andi	First of all, the windmills are pretty easy to explain because we needed power for our city. We wanted to make it environmentally friendly and then, in this game, to be able to access the solar power you need to have very many citizens. So, the windmills are temporary. The idea was to make a copy of our model ((i.e. the physical model)) which would have involved a central solar power plant system here and then windmills here ((pointing out an area in the city)) along the cliff. (.) And, yes, we placed the city beside the cliff also of [it]
103	00:59	Bobbie	[To protect] it against wind catastrophes and tsunamis and similar
104	01:01	Andi	Mm (.) and then we have, we started to lay down a city centre here in the middle, then we started here beside the industrial area, and then we have agricultural all around and the filthy industry far away here...

In this excerpt, Andi starts to describe his group's gaming strategy, by focusing on the power plants in their city proposal, and explains that the windmills were not their first choice. He supports this starting point by

explaining that *we wanted to make it environmentally friendly* (102). But in the same sentence, he clarifies this underlying idea by explaining that *to be able to access the solar plants you need to have many citizens* (102). Andi's statements indicate that the group at the beginning of the game focused on the possibilities to make their city environmentally friendly and sustainable from the start. It is also obvious that the first and best choice, according to Andi, was to use solar power plants, but that the embedded game constraints made this choice impossible, so they had to choose windmills, as the second best option. This interpretation is reinforced when Andi later clarifies that their underlying idea was to model the game proposal on the intended physical model, and by saying that *the windmills* were *temporary* (102). Additionally, he mentions that their physical model was planned to contain a *central solar power plant system* (102), and windmills just as complementing power sources.

The analysis of the students' choice of strategies reveals that the embedded game constraints made the students choose different ways to accomplish a sustainable city in the computer game environment. The first strategy consisted of implementing the most environmentally friendly alternative from the start, by choosing renewable sources of energy. This could, for example, be windmills that generated a relatively small amount of power with relatively high costs. This strategy seems to result in a slow industrial development, slow expansion of population, less income from taxes, and a low level of pollution. When the city budget allowed the students to be more expansive, they still express a will to have environmentally friendly power plants installed. The key arguments for choosing this strategy were supported with statements like, it means *less pollution, renewable power sources* and *climate friendly*. But not all students choose this way of creating a sustainable city. In excerpt D, Manu and Lo discuss the underlying ideas behind their proposal.

Excerpt D

1034	00:34	Interviewer	The mission was to build a sustainable city. How were you thinking when you started it all?
1035	00:50	Manu	We started by building some houses and then a power plant (1.0) yes, and then business zones and industry zones
1036	01:04	Interviewer	What kind of power sources did you chose?

Excerpt D continued

1037	01:08	Manu	Eh (.) I guess it was natural gas.((navigating through the city))
1038	01:13	Lo	And then some windmills. (4.0)
1039	01:20	Manu	There ((pointing out in the city)) (1.0) natural gas (2.0) and then we some windmills
1040	01:31	Interviewer	How come you chose these alternatives, cause there are a lot of other things too, or what is there?
1041	01:36	Lo	Eh, it was, wait, we can check that (2.0) eh (2.0) it was natural gas, and coal which causes a lot of pollution (2.0) so, it is also bad, so it ((i.e. natural gas)) was best for the nature between the choices we had. Then we tried to get a solar power plant system but we needed 3 000 citizens with high income and that we didn't have

This excerpt starts when the interviewer asks Manu and Lo to reflect upon their starting point and their ideas behind their choice of power supply systems. Manu explains that *natural gas* (1037) was their first choice, but at the same time he uses the possibility to navigate in the game environment to be sure that he has given the right answer. Lo confirms the statement, complementing that they also used some *wind mills* (1038). Manu at last find the power plants in the game environment, and confirms that their starting point was to use natural gas and wind mills. When the interviewer asks the students to clarify their ideas behind these choices, Lo fills in that natural gas was the best choice, but also that she is aware that natural gas *also is bad* (1041) for nature. By that she seems to argue that natural gas actually is a more environmentally friendly power source than coal. However, at the end of the excerpt, she explicitly expresses that the aim was to use *solar power plants* (1041), but that *they needed 3,000 high-income earners* (1041) to implement this idea. This reasoning indicates that the students are aware of the fact that the game constraints made it impossible to use the most environmentally friendly power plants from the start, and that they were obliged to choose alternatives that were

problematic in relation to the assignment. This interpretation is reinforced, when Lo expresses that they had to wait in order to use solar power plants.

The analysis of excerpt D and a number of other similar descriptions illustrate the second strategy, which consisted of implementing more cost efficient, but less environmentally friendly energy systems, such as natural gas or coal power plants. It means that the city generates power at a lower cost, but also results in a higher level of pollution. This strategy seems to result in a quicker industrial development, with many citizens moving in. High income from taxes could be generated early in the game, which made it possible more quickly to invest in better alternatives from an environmental point of view. As soon as the city budget allowed it, nearly all student groups replaced coal power plants with more environmentally friendly alternatives. The relationship between efficiency and cost was the most common argument among the students who did not choose environmentally friendly alternatives from the start. Words such as *cost efficiency, profitable* and *changeable* were used in order to argue for choosing such a strategy.

The analysis also made a third strategy explicit. This strategy consists of examples of students trying to find loopholes or ways of getting around the game constraints. One of the student groups discovered that manipulating the monthly costs just before the turn of the month had a positive influence on the city budget. Another group discovered that they gained money every time the fire brigade extinguished a fire, and used the "setting on fire" feature (option in the game) in order to earn extra money. This strategy to increase the city budget, allowing large investment more quickly, was above all used to create possibilities to build environmentally friendly alternatives. The strategy can in some sense be referred to as cheating, but it can also be seen as a creative ability and a competence of being able to penetrate a dynamic system and make the most out of it, in order to fulfil the purpose of the activity.

The results, so far, indicate that the students' choices of power supply systems and retrospective reflections upon their strategies may constitute an educational context, where the computer game environment actually contributes to creating situations, which to some extent could be comparable to real world problems (Figs. 3, 4). This imply that the students, during the game, have to consider and discuss what strategy to choose, and how to balance the consequences of their decisions. Additionally, when reflecting upon their cities, they have to make the underlying ideas behind their choices explicit, which creates possibilities for the teacher to understand and evaluate her students' abilities when it comes to using and applying scientific concepts and theories. We will return to this discussion later on, but first explore in what ways the students experienced limitations and constraints in the game world.

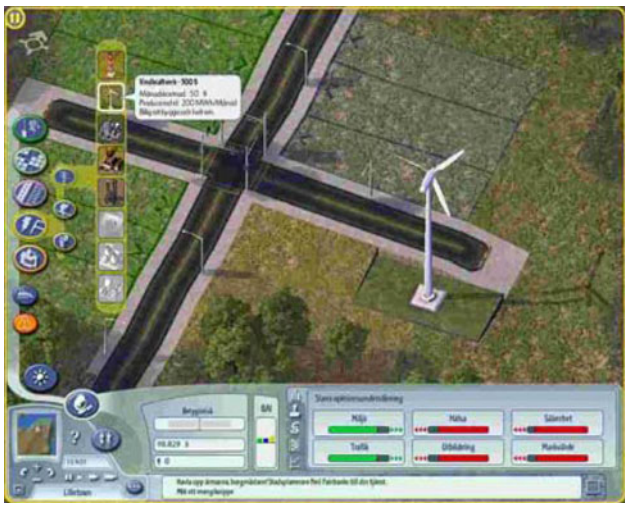

Fig. 3 Windmills that are being installed

Fig. 4 A city created by the students containing solar power plants. (© Electronic Arts Inc. 2003)

Students Commenting on the Limitations and Constraints in the Game World

Another aim in this study is to describe if and in what ways the students experienced any limitations and constraints in the game, with respect to their assignment of building a sustainable city. The analysis of the interviews revealed that several students expressed critical thoughts towards limitations set by the game mechanics (construct of rules). Some students also commented on the fact that the rules in the game are based upon certain American or Western value systems, for example the relationship between tax

income and welfare, criminality and numbers of police stations, structure of street systems and architecture. The analysis showed that these factors limited some students from accomplishing and implementing ideas that could not be framed within the game. In excerpt E, Horst, Milo, and Jovar discuss the kinds of limitations they experienced during the game play, when reflecting on what part of the proposal to choose for their physical model.

Excerpt E

4800	18:00	Interviewer	What part of the city did you choose for the physical model?
4801	18:09	Horst	Some [here] ((demonstrating in the city))
4802	18:10	Milo	[Yes]
4803	18:10	Horst	[That] high hill, the same as we have in our city ((i.e. the physical model))
4804	18:13	Milo	[Yes]
4805	18:13	Jovar	[So, but] the model that we built, the design doesn't have so much to do with the game
4806	18:19	Horst	Because in the game you can't really develop your own thoughts, therefore you have to design your own house yourself ((outside the game))
4807	18:30	Interviewer	Ok, and was it there that you felt really creative or what?
4808	18:37	Milo	[Yes]
4809	18:37	Jovar	[Yes]
4810	18:37	Horst	Yes, here ((the game)) you can't be really creative
4811	18:39	Milo	There are sort of only today's houses available
4812	18:43	Horst	Everything in here already exists in reality
4813	18:45	Milo	You can't really be futuristic. (3.0)
4814	18:51	Interviewer	Ok, but what is being futuristic? Is that what we have seen [today]?
4815	18:54	Milo	[Future]
4816	18:56	Jovar	[Things] that don't exist today
4817	18:57	Milo	Yes, things that you believe will be there in the future
4818	19:01	Horst	Maybe a little bit inspired by science fiction
4819	19:03	Milo	Yes, kind of

This excerpt starts with the interviewer asking the students about what part of the city they *choose for their physical model* (4800), and Jovar's statement that *the design doesn't have so much to do with the game* (4805). In order to clarify Jovar's statement, Horst immediately explains that *you can't really develop your own thoughts* (4806) in the game, and that you *have to design your own house yourself* (4806) outside the game. In these initial statements, it is obvious that the students want to make the interviewer attentive to the fact that is problematic to use their computer game proposal as a model for their physical city project. Jovar's statement also indicates that he perceives the computer game environment as quite separate from the physical model, and that they had to develop their own ideas about how to design their city in the physical version. So far, it is possible to interpret the dialogue as indicating that the students actually focus on the creative part of the design of their physical city as the main assignment.

This interpretation is reinforced, further on, when Horst, as a response to a question, claims that *you can't be really creative* (4810) in the computer game environment. Also, Milo seems to express a will to contribute to the description of the game's limitations by adding that *there are sort of only today's houses available* (4811) in the computer game environment. Horst, additionally, fills in that *everything in here* (the game) *already exists in reality* (4812). By this reasoning, Milo and Horst seem to jointly formulate a serious weakness in the game environment, related to possible alternatives to create a sustainable city in a future perspective. This interpretation is made explicit when Milo in the next sentence expresses that *you can't really be futuristic* (4813) in the game environment. Requested by the interviewer, Milo also shows that he understands the meaning of the word and that he is able to use it in a relevant context.

Discussion

The principal aim of this study has been to explore in what ways students use and apply scientific concepts and

theories when retrospectively reflecting upon their underlying assumptions about a sustainable city in a computer game context. This aim also includes describing students' ideas about different gaming strategies when choosing power supply systems for their cities, and investigating the limitations and constraints they experienced during the game play. The result of the analysis suggests that these reflections, to a considerable extent, helped to make the underlying discussions, choices and decisions explicit. This also means that different understandings and misunderstandings, concerning how the involved concepts and theories could be used and applied to motivate a line of reasoning, were made visible and possible to analyse. The main results of the analysis reveal that the students', above all, related the concept of 'sustainability' to issues concerning quality of life for citizens, which involved ecological, social and economical factors concerning their cities. Most students were actually able to use and apply the embedded scientific concepts in a relevant way. They had employed strategies progressively aiming to use power plants that led to a minimum of environmental problems in their cities. However, the students' reflections also made certain misunderstandings obvious, which to some extent, have also been observed in earlier studies (e.g. Dove 1996; Jeffries et al. 2001; Jakobsson et al. 2009) For example, some students displayed a tendency of confusing the depletion of the ozone layer with the greenhouse effect, or did not express an awareness of the link between the combustion of fossil fuels, carbon oxides and global warming. Additionally, the results of the analysis reveal different levels of student abilities when it comes to using science concepts in a contextualised and complex problem solving situation.

The results clearly indicate that computer games, such as SimCity 4, used in meaningful science classroom contexts, may contribute to create an educational situation where reflections on the embedded scientific content are facilitated and made explicit. One important implication is that computer games can be used to constitute a reflective and meta-cognitive tool, or artefact, that contributes to sensitise the teacher about to what extent the students are able to use and apply scientific concepts and theories in contextualised situations. It is also possible to assume that this process of reflection contributes to enhance and develop students' abilities with respect to these issues. These conclusions are partly confirmed by Stapleton (2004) and Barab et al. (2007), who argue that computer games could be regarded as providers of authentic, meaningful and contextualised educational situations, and that they can be used in order to develop students' understanding of science related issues.

Another result, related to these conclusions, was the students' use of different gaming strategies when choosing power supply systems in order to attain the aim of a sustainable city proposal. The analysis displays that some students choose a strategy of implementing the most environmentally friendly alternatives from the outset, while others started to use power plants based on fossil fuels in order to reach an economic development that made large investments in environmentally friendly alternatives possible. The third strategy involved finding loopholes and ways of getting around the game constraints. The students who chose the first strategy were clearly disadvantaged in the game environment, which resulted in a situation, where their city described a slow development and limited possibilities for action. We have not attempted to evaluate any of the described strategies as better, or more efficient than the others, when it comes to developing an understanding of the science related content. However, we argue that the use of the computer game in this assignment contributed to create a situation where the students had to struggle and overcome complex obstacles in order to build a sustainable city. This implies that they had to articulate, discuss, and find solutions to environmental problems in a contextualised and simulated "real" world, where the game limitations and constraints contributed to preventing the students from using overly simplified solutions to complex issues. This conclusion is reinforced by the fact that when the student groups built physical models of their cities, the corresponding lack of resistance resulted in a situation, where the students risked developing an idealised or simplified understanding of the possibilities of accomplishing a sustainable city.

On the other hand, when the students were given opportunities to comment on the game environment and limitations, some serious criticism was formulated. For example, some students expressed that SimCity is based on American or Western value systems, shown by the relationship between economical development, welfare, and investments in environmentally friendly power plants embedded in the game, or the structure of streets and architecture, which made new solutions impossible. Other students also expressed that the game environment only offers today's solutions and design, and that they find themselves restricted when it comes to using their own creativity in the game. These results are confirmed by Gaber (2007), who claims that computer games such as SimCity are never built from scratch, but are informed by cultural heritage and history, as well as a number of unrealistic assumptions. These severe objections ought to be seriously considered by computer game developers and designers, if they have the ambition that computer games should be used in science classrooms. However, some of these limitations could instead be used as a possibility for the teacher to open a discussion, and a joint reflection on what factors may prevent a development towards a

sustainable city in the real world. Such a discussion could be viewed as a chance to think critically about the underlying science concepts and their implementation in the game design.

Gaber's (2007) argument that computer games contain embedded cultural heritages is in line with a sociocultural framework, which again highlights the necessity of conducting a careful analysis of the underlying content and assumptions in the game. We also contend that this framework could be used to create a theoretical explanation model, in order to understand how people actually develop new knowledge and appropriate new skills and competencies when playing computer games. According to this framework, the game become the meditational means, consisting of cultural products, such as scientific concepts and theories, which to different extents can be used in educational contexts, in order to facilitate mediation of the embedded scientific content. In this study, mediation can be exemplified by the situation where the students use and apply scientific concepts and theories, when reflecting upon their underlying assumptions about a sustainable city in a computer game context. In a theoretical perspective, Wertsch (1991, 2007) describes how our thoughts are mediated by means of tools, signs and artefacts, stating that "mind goes beyond the skin". This statement should not be understood as a way of mystifying the process of learning, but instead as a metaphor, to explain the dialectic relationship between tools, signs and artefacts, and our thoughts. In the computer game environment, this could mean that our thoughts about the embedded scientific content are influenced by playing the game, but also that we are able to influence the game through our thoughts. By playing interactive computer games, this relationship can contribute to drive our understanding of the content, which in turn affects our actions in the game.

As a final conclusion of the study, we argue that computer games, as in this case SimCity 4, actually can contribute to create meaningful educational situations in science classrooms. Computer games can constitute an important artefact that may facilitate and help make students use of scientific concepts and theories explicit and visible. However, a possible weakness related to our study is that we did not study students' interactions and dialogues in authentic classroom situations, which possibly could deepen our understanding about these issues further on. One implication for future studies in this field could therefore be to seek to analyse and describe how students actually act, how they use and apply the embedded scientific content in action, but also how they reflect on using computer games in science classrooms.

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Appendix 1: About Future City

Future City is a national competition for Swedish students in grades 6–9 (ages 12–15), who take on the role of urban planners with the mission to create sustainable cities. Students have to handle matters such as the infrastructure, building constructions, transport system, power sources, etc. The participating students work in teams consisting of fellow students, teachers, and supporting mentors from the industry. According to the organisers (organisations within the building trade), the aims of the competition are: to create an interest for and knowledge about technology, science, engineering, sustainable development; to increase the understanding for the complexity of urban planning; and to be a forum for exchange between teachers, students, engineers and architects. The process is divided into three sequential components: (1) to design and visualise a city by using the urban simulation computer game SimCity 4 (Maxis 2003); (2) to build a physical model of a section of the city designed and visualised in SimCity 4; and (3) to make a written and oral presentation of the city and the assumptions underlying their design choices. Detailed guidelines for how to fulfil the given assignments are introduced to the student groups when they enter the competition. In the school year 2007/2008, more than 1,000 students from 45 schools distributed all over Sweden took part in the event.

Appendix 2: Interview Guide

Interview guide used in the focus group interviews.

- 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 choose 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?

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