シミュレートされた「現実」世界
科学教育におけるゲームと学習に関する博士論文研究の概要
SIMULATED "REAL" WORLDS
Overview of a doctoral thesis on games and learning in science education

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概要　本論文では、科学教育におけるコンピュータゲーム利用の教育的な可能性に関する博士論文研究の概要を紹介する。この研究では、先行研究調査とともにモバイルゲームのAgent Oと市販ゲームのSimCity 4を用いて89名の学習者を対象に3度の実証的調査を行った。その結果、コンピュータゲームの利用によって、科学教育において様々な役割を果たせることが示された。コンピュータゲームは、シミュレートされた複雑な世界と学習者を向き合わせることで、本物の経験を与え、行動を建設的に制約して、科学の実践に夢中で取り組むためのプラットフォームとなり得ることが調査から示された。ゲームが与える行動選択の幅は広く、とても多様な活動ができることから、教師が期待する反応を得られる場合もあれば、まったく期待していない結果に至ることもある。ゲーム中の学習者は、まずゲームで遊んでいるのであり、「現実」世界の状況を模倣しているのではない。特に指導しない限り、学習者はゲームの外の世界で起きていること関連付けて考えることはなかった。結論として、教育の場でコンピュータゲームを用いるうえで、指導の仕方が非常に重要な要素であることを論じた。

Abstract　This paper presents an overview of a doctoral thesis exploring educational potentials of computer game play in science learning contexts. Three empirical studies involving 89 students playing the mobile game *Agent O*, and the COTS game *SimCity 4* have been conducted, as well as a research review. The results suggest a number of ways in which computer game play can play a role in science education. Findings show that computer games may provide platforms for engagement in scientific practice, support authentic experiences, and constructively constrain students' actions, by confronting them with simulated complexities. 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. It is noteworthy that during game play the students in these studies were primarily playing a game, not simulating a "real" world situation. They did not relate to occurrences outside the game world, unless they were specifically instructed to do so. Conclusions further indicate that instruction is a crucial factor, to benefit from potentials of computer game play in educational settings.

キーワード　Science education, learning, mediated actions, empirical studies, Agent O, SimCity 4
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INTRODUCTION

Over the last decade, a great variety of visionary ideas, and beliefs have been brought forward regarding the educational potentials of using computer games as a tool for learning and mediation in educational settings[9, 11, 21, 58]. This paper presents an overview of a recently published doctoral thesis aiming at contributing to 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.

Two tendencies are important as a background to this work. *Firstly*, the rapidly increased use of digital media among young people[34, 43, 50]. *Secondly*, the challenge digital media pose for education[22, 29, 45, 47, 53].

Computer game play in science education

Analytical focus of the three studies is *actions* mediated by computer games, and possible implications for science education. 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[39]. 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[18, 40].

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[12, 22, 31, 51]. It is suggested that computer games have the potential to mediate actions by offering learning contexts where students can engage in scientific practice[1, 4, 5, 48].

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[5]. That is, computer games are claimed to afford such science learning contexts by providing platforms for simulated "real" world situations. However, 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.

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, such as computer games[22, 45, 47, 53]. 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. Today computer game play is a culturally and socially significant activity among young people. In Sweden, nearly all boys (96%), and more than two thirds of the girls (71%) aged 9–16 play computer games[50]. In the rest of Europe, we find similar figures. Almost two thirds of young people1 aged 12–18 play games on PC's, and half of them on game consoles[34].

These experiences have changed the learning and teaching situation for schools. Such 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[24, 29, 52]. As stated by Gee[15], 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" [15 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[12, 17, 27]. Thus, this does not imply that the educational use of computer games is unexplored, only that "research evidence is complex and thinly spread" [21 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" [12 p. 5]. The overall aim of the work presented in this paper is to shed light on some of these areas, where empirical research, so far, has been relatively fragmentary.

THEORETICAL PERSPECTIVE

The theoretical perspective chosen to inform and guide the studies performed is based upon a socio-cultural view of human action and learning[24, 26, 52, 56, 57]. Three basic theoretical 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*. 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[57].

According to a socio-cultural view, human action and learning is situated in societal and cultural contexts, and cannot be extracted from the context in which it occurs[24]. 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[52, 56, 57]. 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[52, 56, 57]. Both the practice in making the tools and using them are passed on, and improved upon from one generation to the next.

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[8]. 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[55]. 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?

AIM OF THE THESIS

The aim 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 during game play.

The research questions aimed at clarifying, in a science learning context, what aspects of scientific practice are:

1) mediated through computer game play,
2) used and referred to by students, when reflecting upon their actions during computer game play.

RESEARCH DESIGN

Empirical studies

Three empirical studies have been conducted involving 89 students (35 girls, 54 boys) aged 13−15. Study I[36] was the initial part in a larger design-based project on mobile learning[20]. The mobile game played, *Agent O*[2, 13] was designed, and implemented by the research team, and based on a platform for global positioning system (GPS) based augmented reality (AR) games developed by the MIT Teacher Education Program, in association with The Education Arcade[13, 23. 49].

Agent O is played outdoors and combines real world experiences with additional information supplied by handheld computers. It is designed to be played in science and technology education, to enhance students' understanding of global interrelations in the area of sustainable development. The quest given to the students consists of solving a mystery involving a fictive story taking place in the hometown. To solve the challenge requires basic scientific reasoning, gathering, and valuing of data, as well as discussing alternative solutions.

Study II[36], and study III[37] were conducted in connection with Future City[14] 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. The designed their cities is the commercial off-the-shelf (COTS) computer game *SimCity 4* [32]. In the game the gamer take on the role of a mayor with the aim to build a flourishing city populated by content citizens handling matters such as power supply systems, infrastructure, building constructions, transport system etc.

Data gathering methods

To increase the *reliability*, that is, the trustworthiness, rigour and quality[16] of the studies performed, various data gathering methods were applied.

In study I and 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.

Data material gathered in study:

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

Data analysis

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

Categories used to code data originated from the transcribed data material itself [bottom up][3], implying that the transcripts produced were analysed without any pre-defined categories. Instead they were scrutinised iteratively and reflexively in a two-phase analysis[41]. 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.

FINDINGS

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"[1 p. 248, 5, 48]. 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" [15 p. 248].

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[37], and to some extent study I[36],

indicates that the gaming students were indeed engaged in scientific inquiry processes, in the sense described above. The analysis 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.

When describing their game play in retrospective, the students in study II[35] mentioned three strategies when choosing power supply system in *SimCity 4*, 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[15], and thus an activity that displays similarities to scientific inquiry processes.

A third strategy observed demonstrates that students explored weaknesses in the underlying game mechanics , referred to as *exploits*[44]. 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. 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.

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[5]. 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. 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. This was obvious, both for students playing *SimCity 4*, a game that some of the students had previously played outside school, and for students playing *Agent O*, which they had never encountered before. The students 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

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.

As previously stated, learning processes are intertwined with the surrounding culture, and constitute a situated practice that cannot be extracted from the context in which they occur[24, 53]. 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[59] 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[28].

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 [12, 6].

Supporting authentic experiences

Theoretically, to situate learning in *authentic* contexts has been seen as favourable for learning[10, 24]. Authentic learning is described as "learning which has a personal meaning and substance for the learner"[33 p. xi]. The question of authenticity is thus a central theme in research on computer games, research on learning research, and science education research [25, 38, 46, 58].

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" [6 p. 122]. Computer games are claimed to have the potentials to provide platforms simulating "real" world situations, and supporting authentic learning experiences [1, 5, 46, 58].

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[15, 48]. *Without* active participation, there can be *no* progression in the game play. As put forward by Squire and Jan[49], 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[27, 30].

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"[1, 5, 48] 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.

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 created in *SimCity 4*, they started to treat them as simulated "real" worlds, relating elements in the game to events in the world outside the game context.

Providing constraints and illustrating complexities

The rules of a game obviously form a framework for potential actions, constraining the gamers' actions[19]. 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[7].

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.

Students were given the assignment to build sustainable cities for the future. 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 *SimCity4* 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.

Final remarks

The results presented in 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" [12 p. 9]. Similar conclusions are also drawn in previous research, stating that the teachers play a significant role[6, 42].

Bearing these points in mind, a productive design for future research would possibly be to involve teachers 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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