Simulating Real-Life Problems in Secondary Science Class

A Socio-scientific Issue Carried through by an Augmented Reality Simulation

Thomas Lundblad, Claes Malmberg, Mats Areskoug and Per Jönsson
Malmö University

With the purpose of developing new methods in science education, the authors combine a socio-scientific issue and game-based technologies from augmented reality games into an intervention activity called Transformer. The authors design the intervention, collect and analyze data, and present results using the three elements from the theory of transformational play (Barab, Gresalfi & Ingram-Goble 2010) namely: engaging and stimulating roles, scientifically relevant content and complex and societally significant context. In Transformer, 20 upper-secondary students engage in a role-play concerning the project of building a school campus area close to a transformer station. The students explore the actual area using simulation-based mobile technologies to collect information through interviews with virtual characters, virtual measurements, and own observations. Collected information is synthesized into arguments concerning the appropriateness of building the campus area. The Transformer activity is based on SSI (socio-scientific issue), a pedagogical model aiming at developing students' competences to make well-informed decisions through engaging them in complex societal issues.

Data from the intervention are collected with multiple methods using questionnaires and interviews. The analysis illustrates expressions of immersive role play and active and engaged students who enjoy the opportunity of working in groups with a challenging task outside the class room. For some

Lundblad, Thomas, Claes Malmberg, Mats Areskoug & Per Jönsson. "Simulating Real-Life Problems in Secondary Science Class: A Socio-scientific Issue Carried through by an Augmented Reality Simulation." *HUMAN **IT*** 12.2(2012): 1–41. © The authors. Published by the University of Borås.

roles, however, there is room for improvement in the outdoor part of the intervention. We argue that this design perspective makes it feasible for a teacher or team of teachers to stage a multi-disciplinary engaging intervention that is constructively aligned with the students' and teachers' own practices and that addresses curricular goals.

Keywords: augmented reality (AR), design-based research, science education, socio-scientific issue (SSI), upper-secondary education

The downward trend in the recruitment of students in science-related subjects is a concern for politicians, policymakers and researchers. One reason for this trend, according to Dillon and Osborne (2008), is that science education is not conceived as an education for the majority of students. Instead, it is targeted at supplying society with future scientists, while ignoring the broader group who need science education in order to become responsible citizens and make informed decisions about issues concerning our current and future society. McWilliam, Poronnik, and Taylor (2008) suggest re-designing science education by introducing more creative and engaging pedagogies. Brown's notion of identity-forming activities, "learning to be", rather than merely "learning about" (Brown 2006), is used as a starting point for their arguments. Sadler (2009) emphasizes the importance of students having the possibility to learn science in a community where they can be central participants and express their identities. In an education that departs from the science discipline, students have little chance of participating and expressing their identities. But, according to Sadler (2009), if the teaching is framed by issues that are important to the students themselves, they become more central participants. Their chances of meaning-making and expressing their identities – and therefore also of learning – increase. Participating in communities of practice during their education may provide students with a foundation that enables them to become informed actors in a challenging future.

> *In peripheral participation the student is engaged in real work. ... He or she is able … to pick up, as through osmosis, the sensibilities, beliefs, and idiosyncrasies of the particular community of practice. Learning happens seamlessly as part of an enculturation process as the learner moves from the periphery to a more central position in the community.* (Brown 2006, 20)

Socio-scientific issues (SSI) are brought forward by Sadler (2009) as a pedagogical model to establish communities of practice where students' identities can be expressed and where they can use previously-appropriated knowledge. Work with SSI is often said to engage students in developing scientific knowledge as well as their interest in society, since SSIs are characterized by complex tasks based on topical media-reported issues. The work model involves the forming of opinion through ethical evaluations, risk assessments and cost-benefit evaluations.

The challenge for science educators to engage students in authentic problems where they develop scientific knowledge is also met by another pedagogical model. Game-based learning approaches have been suggested as one model that might situate students in complex problems based on authentic questions and incorporating multiple tools and resources. One type of games put forward are augmented reality (AR) simulations (Squire & Klopfer 2007). In AR, learning goals can be tied to particular places and allow for embedding authentic resources and tools that are useful within the context of the simulation. Within these simulations, students interact with each other and with the environment around them. AR enables students to see the world around them in new ways and to engage with realistic issues in a context with which the students are already connected.

This article describes the design, testing and evaluation of a pedagogical tool in the form of an intervention called Transformer aimed at engaging secondary school students in science through challenging real life problems. The intervention combines socio-scientific issues (SSI) and augmented reality (AR) technology through a design-based research approach.

Theoretical Background

Socio-scientific Issues

A growing awareness of the impact of science on society and the social, moral, and ethical dimensions of science calls for a science education aiming at scientific literacy (Gray & Bryce 2006) in a re-thinked way, as Roth and Lee (2004) discuss. They express the need for working with science as one tool among others in the handling of everyday life. An education that deals with socio-scientific issues (SSI) is said to help students to develop competences such as informed decision-making, argumentation and discussion that are valuable tools when they need to make choices and take standpoints in everyday life. Research and policy are emphasizing the importance of scientific literacy in terms of a competence to use science knowledge in everyday life (e.g. European Commission 2004; Sjøberg & Schreiner 2005). SSI is one teaching approach, among others, pointed out as a tool to develop young people's competence to use science knowledge in solving societal problems and to raise their interest in science. Ratcliffe and Grace (2003, 1) define SSI as issues that have a "basis in science and have a potentially large impact on society". An aim with SSI is to engage students in both formal and informal reasoning, using their knowledge about scientific aspects combined with their personal values concerning the issue. The approach emphasizes dialogue. Working with a SSI will usually involve students' skills in science reasoning and the ability to evaluate relevance and reliability of information and evidence. The process is intended to give the students opportunity to develop collaboration skills and deepen their conceptual understanding of different factors affecting the issue.

Ratcliffe and Grace (2003) point out a number of central learning goals that they categorise in *conceptual knowledge*, *procedural knowledge,* and *attitudes and beliefs*. The learning goals concerning conceptual knowledge involve the nature of scientific endeavour, probability and risk and environmental sustainability, and goals connected to the scope of the issue (personal, local and global perspectives) and the societal and political context. It means that an intervention founded on SSI should consider the topicality, the complexity and the societal and scientific aspects of the content. Goals connected to procedural knowledge concern students' engagement in evaluation of the trustworthiness of information, discussion of cost-benefit aspects, ethical reasoning etc. A SSI intervention should therefore place students in situations in which they can experience, e.g., decision-making using a partial and possibly biased information base. Attitudes and beliefs is the third category of goals. It deals with personal and societal values in considering the issue. The student should recognize how values and beliefs are brought to bear, alongside other factors. To reach this goal, a SSI should deal with different personal views and also involve a conflict between different groups of interest. This is in line with what Sadler (2009) brings forward. SSI can be regarded as a way to open up communities of practice (Lave & Wenger 1991) where students become members and where their identities can be expressed and where they can use previously appropriated discourses. Working with SSI is for this reason characterized as making school science important and usable outside the classroom and outside the scientific discourse. It should, according to Sadler, therefore be an engaging community of practice where students have the opportunity to participate and be included in a more general discourse on issues other than the specific and abstract science discourse.

Augmented Reality (AR) Simulation

Many areas of education could benefit from designed games concerning different topics from the curriculum since gamers get immersed in problem-solving, collaboration, decision-making and discussion (Shaffer *et al.* 2005). Squire (2006, 26) argues that "educators might profit by studying these designed experiences, experiences resulting from the intersection of design constraints and players' intentions". In contemporary games for learning, the player is often placed in a context, allowing participants to create their own learning trajectories. Shaffer (2006) brings forward the concept of "epistemic frames", to shed light on how students can use experiences from games to deal with situations in the real world and vice versa. The concept is based on the same idea that Sadler put forward in connection with SSI. A game can be regarded as a community of practice (Lave & Wenger 1991) with a specific culture composed of skills, knowledge, identity, values and epistemology (how community members make decisions and justify their choices). Epistemic games use authentic professional practices to teach students complex problem-solving. Players learn through taking action and then reflecting on what they have done with others involved in the game.

Games and simulations in the AR domain have been developed at the Teacher Education Program at the Massachusetts Institute of Technology (MIT) (Klopfer & Squire 2008; Rosenbaum, Klopfer & Perry 2007; Squire & Klopfer 2007). In these games, each group of students uses a handheld computer with which they collect information and collaborate with other groups and persons, both real and virtual. They navigate in a real environment with the use of a digital map and GPS-based guiding. The participants can act both in the real world, by making observations and interviews, and in the virtual world, by taking samples and making measurements. This combination of real and virtual worlds has the advantages that the game is experienced as authentic for the players (compared to computer games), and at the same time it compresses the time-rate, thereby making it possible to conclude a game in a reasonable amount of time in a school context. In an augmented reality game played today, depending on available resources, the players could use smart phones as their "game-boards". According to Klopfer (2008, 95), a handheld computer (corresponding to an up-to-date smart phone) has certain advantages such as:

- portability – opportunity to take the computer/phone to different sites and move around within a location,
- social interactivity – prospect to exchange data and collaborate with other people face-to-face,
- context sensitivity – possibility to gather data unique to the current location, environment and time, including both real and simulated data,
- connectivity – possibility to connect handhelds to data collection devices, other handhelds, and to a common network that creates a true shared environment, and
- individuality – opportunity to provide unique scaffolding that is customized to the individual's path of investigation.

These advantages are visible in the theory of transformational play, developed by Barab, Gresalfi and Ingram-Goble (2010). The theory takes into account how to offer experiences that they wish to put forward through their designs. Transformational play assumes that students, content, and context are bound together. They position students as active decision makers who use their knowledge to make inquiries and to change things. Playing transformationally involves:

> *(a) taking on the role of a protagonist (b) who must employ conceptual understandings (c) to make choices (d) that have the potential to transform (e) a problem-based fictional context and ultimately (f) the player's understanding of the content as well as of (g) herself as someone who has used academic content to address a socially significant problem.* (Barab, Gresalfi & Ingram-Goble 2010, 526)

More specifically, the theory connects three elements: student, content, and context.

Design-Based Research

One purpose of design-based research is to develop knowledge about how students learn and about the means that are designed to support that learning (Cobb *et al.* 2003). Design studies are therefore test-beds for innovation with the intention to improve education by bringing in e.g. new technology with the purpose to mediate learning. In this process "humble theories" (ibid., 10) might be generated or refuted. The theories are pragmatic in that they are aiming at informing teachers' practice. If the theories are refuted new ones need to be developed and tested. It results in an iterative design process involving cycles of invention and revision.

Starting with the seminal work of Brown (1992) and Collins (1992), design-based research has developed into an approach which "provides an opportunity for educational researchers to draw on contemporary research on teaching and learning to create new designs that, if they are successful, could achieve broad, direct impact" (Edelson 2002, 119). Through continuous development and refinement by researchers (e.g., Barab & Squire 2004; Cobb *et al.* 2003; Collins, Joseph & Bielaczyc 2004; Design-Based Research Collaborative 2003; Edelson 2002; Gravemeijer & Cobb 2006; Kelly, Lesh & Baek 2008), design-based research has come to fill a vital niche in the body of experimental methods, needed to improve educational practices. Cobb *et al.* have summarized the approach as follows:

> *Prototypically, design experiments entail both "engineering" particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them. This designed context is subject to test and revision, and the successive iterations that result play a role similar to that of systematic variation in experiment.* (Cobb *et al.* 2003, 9)

In the current study a simulation is developed (Transformer) which will be described in detail further on. This simulation is used by a science class at an upper secondary school. The study describes the background, the implementation of the simulation and results from the first cycle of an iterative design – research process.

Aim and Questions

The aim of this study is to design and evaluate an AR-simulation, Transformer, with learning goals and methods derived from SSI. The study is intended to be one step in an iterative design cycle. The questions this study is trying to answer are strongly connected to the three elements of the theory of transformational play. How can an AR-game on a socio-scientific issue be designed and realized so that a) the roles will engage the students and stimulate them to activity, b) the content will be relevant with respect to the students' scientific education, and c) the students get the opportunity to affect a complex, socially significant problem?

The thoughts and choices behind the design process and construction of the simulation will be described in the next section, "The AR-Game". Thus the first part of the questions will be treated: *how* can an AR-simulation on a socio-scientific issue be designed and realized.

The second part of the questions, whether the game fulfils the conditions posed, are investigated with methods described in the "Method" section and discussed in the following "Analysis and Results". A deeper study of the students' use of scientific knowledge in the game is treated in another article with the preliminary title "Dialogic Manifestation of an Augmented Reality Situation" (Lundblad *et al.* submitted).

The AR-Game

This study focuses on the first step in an iterative design cycle of the simulation Transformer. Thus the choices behind the construction of the simulation and an analysis of the students' work with it will be treated.

Design of the Game

The theory of transformational play (Barab, Gresalfi & Ingram-Goble 2010) and the teaching approach socio-scientific issues (SSI) (Ratcliffe & Grace 2003) have been important for the design of the simulation presented here, called Transformer. The simulation has been implemented at an upper-secondary school in Sweden. Transformer deals with an authentic dilemma concerning the expansion of a school campus area close to a transformer station. Figure 1 shows a view from one of the school buildings with the transformer station in the front and another school building in the background.

Figure 1. The location of the transformer station close to, and between, two of the school buildings.

The story in Transformer was based on a decision by the head of the school to expand the school campus, with the aim of connecting different school buildings with spaces for the students to spend their free time outdoors. Lawns, benches and tables, a small stage, and other spots for students to meet were under construction. The dilemma was the transformer station. *Is it advisable to build a campus area, where students spend* *some of their school day, close to a transformer station with high power cables emitting electromagnetic fields, EMF?* Research on health risks concerning extremely low frequency fields (ELF), as those from power lines, is ambiguous. With 25 years of research into possible health risks from ELF fields, much knowledge have been gained, but considerable scientific uncertainties still remain. Biological effects on the nervous system have been identified and are reported in a World Health Organization (WHO) report concerning ELF (WHO 2007). Studies suggest that everyday low-intensity ELF magnetic field exposure may increase a risk of childhood leukaemia. In the same WHO report, the following is put forward:

> *Given the weakness of evidence for a link between exposure of ELF magnetic fields and childhood leukaemia and the limited potential impact on public health, the benefits of exposure reduction on health are unclear and thus the cost of reducing exposure should be very low.* (WHO 2007, 372)

The students involved in the simulation were not expected to find a single "correct" answer. Rather, the students had to make their own decisions, balancing scientific, societal, environmental, economic and aesthetic factors and information.

Transformer was designed for group work. Each group took on one of five different roles: journalist, environmental scientist, technician, project leader and chairman of student organisation. They investigated the area surrounding the school using GPS guidance and collected different sorts of available information that might be useful in making a decision about the question at stake. In the process of reaching a decision, the students had to perform complex argumentation within their groups as they explored the area (Figure 2).

Figure 2. A Google Map excerpt showing the area (500m x 500m) which the students explored, collecting information. Residential districts to the right and upper left and a football stadium at the top.

Transformer consisted of three parts:

1) collecting information outdoors, where the transformer station is situated, for one hour using fictional interviews, virtual measurements, and the students' own senses;
2) two hours of indoor work in their roles, collecting additional information and forming their arguments; and
3) a one hour debate, where the students in their different roles argue for their standpoint and finally take a vote on the question at stake.

The design used in Transformer has treated the requirements from the research questions in three parts: engaging and stimulating roles, scientifically relevant content and complex and societally significant context. These parts are described below.

Construction of Roles

To imbue the students with the feeling of "learning to be" in the sense of working with a science-related task, we chose to let the story unfold in a real environment with a real, actual problem: building a campus area close to a transformer station. The students moved around in the contested area outside their school, collecting information. The casting in Transformer consisted of five roles: Journalist; Chairman of the student organization; Technician at the city's Environmental Department; Project leader at the Power Company; and Engineer at the Swedish Radiation Safety Authority. The characters of the five roles were chosen in order to make the players adopt different standpoints in the question at stake. Effort was made to give the players equal strength to support the conflicting interests. The roles as Journalist and Chairman were more societally oriented, while the other three were more science oriented. The assumption at the design phase was that the Journalist and the Chairman of the student organization were against the building of the campus area, the Project leader and Environmental technician were positive, and the Engineer was somewhere in between. Another intention at the design level has been to include roles that would shed light on perspectives at different societal levels. The Chairman represented the local level, with knowledge and feelings for the immediate surroundings. The Journalist and the Environmental technician acted on a city level, with beliefs and concerns relating to the inhabitants of the city. The Project leader acted on a business level, representing a company with customers all around Sweden and with an interest in making profit. Finally, the Engineer represented the national level, governed by legislation and international treaties. Depending on their role, the players had different sources of information available and different tasks to fulfil.

For the roles of Journalist and Chairman, the main source of information consisted of interviews with Non Playing Characters (NPCs) scattered over the area, as well as possible "live" informants they might meet. The other three roles – Technician, Project leader, and Engineer – had the ability to make virtual measurements of electromagnetic radiation levels combined with interviews with NPCs as their main sources of information. The Chairman and Journalist roles were given the following task description:

> *The school is building a campus area for the students. Within the area, a large transformer station is situated. What arguments speak for and against such a project? Is the transformer station dangerous? What is the public opinion? What does research in this area say? How has the city authorities argued?*

For the Project leader, Technician and Engineer, the task description was formulated as:

> *In connection with the construction of a campus area around the school there have been critical views about the fact that there is a transformer station in the middle of all this. Take measurements and collect impressions and information to be able to meet the critics.*

To stimulate the engagement in the role play the students were asked to write a short fictitious description of their character one week before the intervention. Name, age, education, career, family and interests outside work were described by the students in a short text.

Scientifically Relevant Content

To give the students the opportunity to act and deal with science concepts and methods we have used a socio-scientific issue (SSI) approach. As described above, Transformer deals with risks connected with electromagnetic fields (EMF). EMF have many sources in our everyday environment. Technical appliances such as mobile phones, radio and television broadcasts all use high-frequency EMF for communication purposes over large distances. Every household product with a floating electrical current emits an electromagnetic field. Power lines, which are the main issue in the game Transformer, are surrounded by an alternating magnetic field, spreading out radially, and decreasing with distance from the power line. As mentioned, research in health risks concerning extremely low frequency fields (ELF), as those from power lines, is somewhat ambiguous. In a report issued by WHO's EMF project, the Health Risk Assessment part concludes that ELF may have adverse consequences on health, but the evidence for a causal relationship is limited (WHO 2009). The Swedish Radiation Safety Authority (SRSA) states on their website that the strength of harmful magnetic fields lies way over values normally existing in our environment and recommends that placing schools and kindergartens close to electrical facilities should be avoided due to the uncertainty concerning childhood leukaemia and exposure to magnetic fields from power lines (SRSA 2010a; 2010b). The students thereby meet uncertainty concerning ELF in guidelines given from national and international bodies and need to explore this in Transformer.

The emphasis on conceptual and procedural knowledge, as well as attitudes and beliefs, is somewhat different in the various roles during the outdoor part. However, once engaged in forming arguments, all three parts are equally relevant and in action.

To involve the students in informal reasoning, typical for an SSI (Sadler 2004), we designed 13 NPCs to interview during the outdoor part of the intervention. The NPCs were distributed among different roles, as shown in Table 1.

Non Playing Characters (NPCs)	**Roles**				
	Journalist	Chairman	Project leader	Engineer	Technician
Björn – headmaster	x	x		x	x
Anna – former student		x			
Britta – resident in the area	x	x	x	x	x
Elma – director at the power company	x	x		x	x
Elvis – student at the aesthetic programme	x	x		x	
Erik – official from the city's planning office	x	x	x	x	
Gustav – the school's chief of development	x	x			
Jenny – school teacher	x	x			
Kristina – resident in the area	x	x	x		x
Lars – doctor at the hospital	x	x			
Miranda – student on the social science programme	x	x	x	x	x
Stella – student on the aesthetic programme	x	x	x	x	x
Olof – physics teacher	x	x	x	x	x

Table 1. The distribution of available NPCs to interview for each role.

The three roles with measuring capabilities, Engineer, Technician, and Project leader have fewer NPCs available for interviews (see Table 1). Their biggest challenge was instead to map the area concerning radiation levels. For each measurement, these role characters had to choose between a quick-test with 15sec. acquisition time and 70 % accuracy, or a precision test with 30sec. acquisition time and 95 % accuracy. This choice of measuring method has been introduced to encourage discussions concerning measuring strategies, accuracy, and reliability. During the game, the students have to find the limits and borders of radiation, and are forced to work in a scientific way to achieve an accurate description of the situation. The possibility to take measurements of electromagnetic radiation was available throughout the whole area, but the ELF is confined within an area of 80m radius, centred at the transformer station. Levels of radiation peak at the centre of the transformer station, with a drop-off to a pre-defined border, 80m away. The location of the ELF and its borders were not visible to the students, but the location of the source of radiation was quite obvious. Close to the starting point, the students had the possibility of collecting information about a threshold value of ELF suggested by the Swedish Radiation Safety Authority.

The SSI approach concerning the content of the intervention was consistent with the Swedish curriculum and gave the students the opportunity to address subject-specific curricular goals as well as goals about developing the ability to see relationships between natural sciences and other sciences. From a pedagogical point of view, Transformer offered a platform for both learning and assessment. The students learned by engaging in active role playing, trying to substantiate their arguments with relevant facts. The teachers had the opportunity to formatively assess the students by observing their actions during the different parts of the intervention and by reading and listening to the arguments that they presented. The students' skills could also be assessed by different subject teachers, since they apply elements from both the natural and the social sciences, as well as demonstrating their oral presentation skills.

Complex and Socially Significant Problem

The context in Transformer was constituted by the environment outside the students' school buildings (see Figures 1 and 2). The transformer station was situated between the school buildings and its various components can be both seen and heard from the school area. The design used this strong local connection, combined with the possibility that the ELF from the transformer station may impact the students' own health, in order to highlight the consequences of the students' decisions concerning the construction of the campus area. The possibility to investigate, discuss, and form an opinion about something that is close and topical to the students themselves is expected to invest their actions with meaning. All the way through Transformer, the students worked in groups of two or three to stimulate discussion and collaboration. Outside the classroom, the groups worked independently without any teacher scaffolding which means that they had to make their own decisions concerning which strategy to adopt in collecting information.

The MITAR Editor

In the construction of the outdoor part of the intervention, we have used the Massachusetts Institute of Technology Augmented Reality editor (MITAR), which is free of charge and can be downloaded from their website. In our design, Transformer is more of a simulation than a game. We use most of the advantages with handheld mobile devices mentioned in the Background section but above all to deliver the context and content to the students, rather than with the intention of immersing them into a game. Compared to other types of games, a simulation has strong connections to reality. It is not necessarily a contest or competition, and the participants do not necessarily strive to win (Sauvé *et al.* 2007).

In Transformer, each role uses a smart phone equipped with the MITAR Engine, which is the software application that delivers the simulation designed in the MITAR Editor. In the editor, installed on a computer, the designer chooses a map from Google maps showing the area of interest. Our map covers an area of approximately 500m x 500m, confining the area of interest and considered possible to explore in one hour. The different NPCs are placed at appropriate locations depending on the narrative and given a dialog to deliver when the students reach the NPC's location. Both the placement of the NPCs and the dialog they deliver differ slightly for different roles. This is to induce the notion that there is more than one "correct way to do this". The different roles have to decide their own path through the area. Figures 3 and 4 show the smart phone screen with the game map for two of the roles, indicating available NPCs marked with yellow dots. The Project leader role has measuring capabilities, but fewer interviews available compared to the Journalist role. The orange dot marks the students' present location and moves across the map following the group's progression in real time.

Figure 3. The map tab view for the Journalist group with NPCs (yellow dots) to interview and their own location in the area (orange dot).

Figure 4. The map tab view for the Project leader group with NPCs (yellow dots) to interview and their own location in the area (orange dot). Tapping the Take Sample button starts the measurement procedure.

The interviews with the NPCs are designed to expose students to the diversity of opinions that exist concerning this issue. While "talking" to the NPC, information was transferred to the players through texts, excerpts of documents, and through references to other sources of information. These sources could be other NPCs in the game, live persons to contact after game-play, or sites on the Internet with relevant information. All the interviews in the game were pre-loaded in smart phones for each role, and could not be changed during the game. For instance, chief education officer Björn introduces the tough competition that exists between municipal and private schools as a motive for expanding the campus area.

Björn (B): So you want to ask some questions. Ok, a short interview then. I'm on my way to a meeting so let's get on with it.
Players (P): Why are you building this campus area? Aren't you worried about the students' health when there is a transformer station so close?
B: If we're going to compete with the private upper secondary schools we must create a nice outdoor environment where the students can spend their breaks and lunches. The private schools can choose their locations quite freely; we have to work with what we've got. The transformer station has been situated here for a long time. If it had been dangerous, they wouldn't have built it in the first place.
P: How much does this really cost?
B: I'm not sure. You'll have to ask our chief of development, Gustav Andersson.

Björn is visible to the Journalist, the Chairman, the Engineer and the Environmental technician. After interviewing Björn, Gustav becomes visible to the Journalist and the Chairman in two role specific versions, one for each role. For the Journalist, the interview with Gustav evolves as follows:

Gustav (G): Hi. Journalists from HD [local paper]. Woops, the fourth estate is here, I'd better watch out.
Journalist (J): We spoke with your boss a while ago and when we asked about the costs involving the campus area he referred to you. How much has the school invested in this?
G: This project is conducted in collaboration with another municipal company and they take on the major part. I don't have the exact figures.
J: Somebody in the organization must know what this costs?
G: Ask Hans-Jörgen Roth, our head of administration. He should know.

This sequence of the game aims to give players an authentic view of problems that occur when you try to collect information, looking for the right persons to ask. It also points to the possibility for the players to conduct interviews with real persons outside the game, since Hans-Jörgen is not an NPC. When interviewing Kristina (Figure 5), acting as a resident close to the transformer station, the players not only receive her personal opinion but also a link to an Internet site with additional information.

> *Kristina (K): I heard that you are asking people about the transformer station over there. I've always been worried about that one. I walk this way every day on my way to work and back. I usually walk my dog here as well.*
> *P: What's worrying you?*
> *K: I read something about radiation some years ago and I tried to find out some more. I found a website on the Internet called breastcancerfund.org. You can see for yourself. It got me worried anyway.*

Figure 5. The students' screen when they reach Kristina's location outside. By tapping the arrow they can read the interview.

By tapping the different tabs on the screen, the students could switch between Map tab, People tab, Item tab and Samples tab. The Map tab showed the contested area, with possible NPCs to interview (Figures 3 and 4). In People tab mode, the students could review each of the interviews they had made. In Items tab mode, collected items in the simulation could be reviewed (however, no items were used in Transformer). By tapping the Take sample button, the students entered the sample dialog screen, where they had to decide which emission they wanted to measure, and which measuring method to use. Once the sample had been processed, the result and the location of the measurement appeared under the Samples tab. Following the narrative in Transformer, we have used only one type of emission: the level of the electromagnetic field close to the transformer station. Nevertheless, to trigger discussions in the group, students had to choose between a faster, less accurate method of measurement, and a slower, more accurate method. After the one hour time limit, no more interviews and measurements could be made. However, all results from measurements and interviews could be reviewed in Sample tab and People tab mode.

Using the MITAR engine and editor provided us with the tools to engage the students in the process of collecting virtual information, as well as making their own observations in the area in question. Students also needed to collaborate within their group, deciding which strategy to use concerning measurements and interviews. This strategy had to be reconsidered with each new piece of information collected. From a pedagogical point of view, MITAR framed the activity and confined it to a specific area, with specific tools to use. At the same time it opened up for the students to act and follow their own decisions and the consequences of these within the frame set by the design. The time limit of one hour had a dual purpose. It challenged the students to be rational and focused on their task, while also giving teachers the possibility to plan the whole intervention and fit it into a normal school day.

Methods

Context of the Intervention

The students in the intervention attended the Natural Science Programme (Naturvetenskapsprogrammet), which aims at providing scientifically based knowledge of the conditions of life and of nature (Skolverket 2011). An additional aim in the programme is to develop the ability to see relationships between the natural sciences and other sciences. The programme primarily lays the foundation for further studies. The specific subject content of the game Transformer – health effects from electromagnetic fields from a transformer station – mainly corresponds to three learning goals in the curriculum:

- *Have knowledge of electrical and magnetic fields … and be able to describe some applications …*
- *Ability to describe and analyse everyday, medical and technical applications, using physical concepts and methods*
- *Ability to discuss environmental and ethical issues connected to physics* (Skolverket 2011)

The students in the study reported here were attending the third and last year of their studies and belonged to a class of 32 students. For practical reasons, the teachers divided the class into two sets of 16 students. The class as a whole represented a socio-economic average with students from all parts of the school's uptake area. The participants' ages ranged from 18 to 19. The class of students was taught by a team of teachers which included the first author of this article. This helped facilitate the implementation of the intervention and avoid the common teacher resistance against disturbances in the timetable.

Pre-test of the Intervention

Several elements of the first phase of design have already been described above. As one step of the iterative design process, a small trial run was carried out with ten students to check the functionality of the smart phones, GPS-coverage etc. We also wanted to know if students had any trouble using the phones to navigate, make interviews and measurements. The trial run did not use any narrative to engage the students. They just took a small walk for about 15 minutes, making two interviews and one measurement, without any connections to the transformer station. One of the interviews contained a video clip with some guidance advice for the trial run. From this test, we learned that looking at and listening to a video delivered through a small screen outdoors with traffic noise in the background was difficult to do in a group. Also, reading longer texts from official documents was impractical and took too long. Based on these results, we decided to keep the information collection fast-paced by using dialog-based interviews with comparatively short questions and answers.

Data Collection

The research questions of this study deal with students' engagement in the game and what opportunities the game provides for students to handle a complex and socially significant problem. The first author of the article collected the empirical data. He was a teacher at the school, although not for the students involved in the study. The data consist of material from observations of two groups during the outdoor part; student reports from group debriefings after the outdoor part; and one questionnaire and a set of semi-structured interviews conducted after the whole intervention. The study is the first step in an iterative design cycle of the simulation Transformer with the purpose to develop knowledge about how students learn and about the means that are designed to support that learning. It is not a full-scale empirical study but should rather be perceived as a test-bed for innovation with the intention to improve education.

The questionnaire was designed to probe students' experiences and impressions from the outdoor part of the intervention. It consisted of 59 statements in a Likert scale, ranging from strongly disagree, disagree, undecided, agree, to strongly agree. Not all of the statements are relevant for the research questions of this study. The list of statements was arranged in random order, with positive and negative statements intermingled. The large number of questions in the questionnaire is due to the fact that various questions in different parts of the questionnaire deal with the same problem. Comparing the answers may strengthen the reliability. Questions with similar focus but different formulations may confirm the validity. Also, the triangulation, using interviews (and also observations and student reports) make the results more reliable.

In the outdoor part of the intervention, 24 players participated. Two of the players did not want to participate in the research part of the intervention, and two students never handed in their answers. This resulted in a total of 20 respondents to the questionnaire. It was delivered a week after the outdoor part.

Of the 20 students participating in all parts of the intervention, 5 were chosen for the semi-structured interviews. The interviews probed deeper into the students' experiences from Transformer, trying to triangulate earlier findings. These interviews were conducted five months after Transformer, mainly to substantiate the findings, but also to be able to assess the long term effects of the intervention. Respondents were selected among the participants in a manner that permitted the collection of experiences from different roles, gender, and levels of motivation towards science learning. The interviews were fully transcribed and analysed in light of the theory of transformational play with respect to the requirements of the research questions; engaging and stimulating roles, scientifically relevant content, and complex and socially significant problem.

To monitor students' work outdoors, two groups were observed, and their actions were recorded in short field notes. Students' reports from their work after the outdoor part were collected to evaluate how they substantiated their arguments. Ten reports were collected, one from each role in the two sets of students.

In the transcripts of the interviews the essence of what the students said has been considered, the Swedish expression has been translated into a colloquial informal English expression since the empirical material consists of statements by upper-secondary students.

Ethical Considerations

The project followed established ethical guidelines used by the researchers' university. All the students gave their consent and were informed of the aim of the study. Pseudonyms have been used for the students for anonymity.

Analysis and Results

Although we are still at an early stage of the design process we argue that the outcomes provide an indication that our design perspective can be applied in other educational environments. The detailed description above, combined with selected excerpts from interviews and questionnaires below, grouped in accordance with the research questions (and thus also with the elements of transformational play), are intended to provide the reader with the means to determine how elements of this experience might apply to the reader's own situation. Subsequent stages of the design-based research cycle will be informed by lessons from this first phase.

Engaging and Stimulating Roles

Observations during the intervention showed that students took great responsibility and were strongly engaged in their activities. In the interview, Susanna gave vivid evidence of her high level of engagement and her notion of doing something real.

Interviewer: Do you think you inhabited your role?
Susanna: Yes, I think so. You held that thing [the smart phone] and then you followed, and then you felt – ooo now I have to find that person, even though they only were a dot on that map. So when you got an answer – ooo write the answer down, because he is telling us, it was almost like that. So when you found out – yes but we must check the levels here, and so on. I really felt that one was immersed in it, especially since we were outdoors and we followed, it was really, the map was exactly as it was in reality, it was according to scale, so it actually felt real. (Technician)

Her experience of playing an active part in solving an interesting problem is further substantiated with results from the questionnaire. Figure 6 below shows that a great majority of the students who answered the questionnaire felt that they played a part in the game and that they were very active. They became engaged by the possibilities to search information actively, provided by the game.

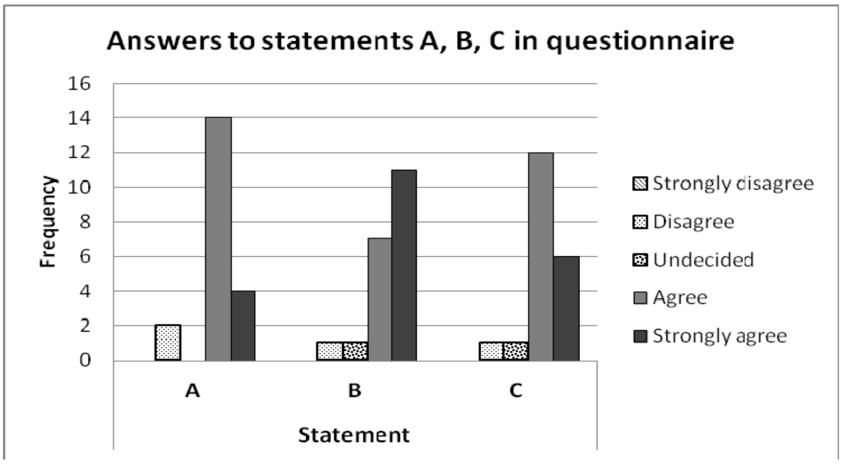

Figure 6. Frequency of answers to the following questions (n=20):
A: I felt I played a part in the game
B: I was very active in collecting information
C: The game made the problem interesting

Scientifically Relevant Content

The content in Transformer was presented in the context of an SSI, addressing both conceptual and procedural knowledge, as well as the students' attitudes and beliefs. The roles with measuring capabilities met fewer NPCs, and instead had measurements as their main source of information. The groups who played these roles had to evaluate and plan their measuring strategy concerning where to take measurements and which method to use (slower and more accurate, or quicker and less accurate).

> *Interviewer: How did you reason concerning the two different methods of measurement? How did you choose?*
> *Steven: The quick one was quick but the slow one wasn't that slow either, so we took quick ones close to the school. When it started to increase and it felt like a relevant distance, we took more accurate measurements.* (Project leader)

Constrained by the time limit of one hour, this group tried the two methods available, and developed a plan to cover the relevant area with measurements. They have to take into account the dependence of the radiation level on the distance from the source. Investigating this, they have to make choices on the measuring methods, balancing on the one hand the need for more measuring points and on the other hand more accurate measurements.

In the following excerpt, Robert shifts between the notion of himself playing a role in the game, and himself as a person, thinking for himself.

> *Interviewer: Was there anything in your role that you think was typically science?*
> *Robert: The problem itself has rather strong science parts, with the effect of the transformer station on the surroundings. But in my role as such, I didn't need to have any science … well maybe if one shall think for oneself it could be useful to have some knowledge about it, but we had the opportunity to*

contact experts in the area. I as a role maybe didn't need to have any science skills, but it deals with a problem with science parts. (Journalist)

Robert expresses that if he is confined to his role he does not need any science knowledge, since he plays the role of a journalist. On the other hand, if he were to "play himself" in the game, science skills would have been useful. Robert realizes that if you are going to handle the question of building the campus area in "reality", you need knowledge of the physical world, but for himself, confined in his role as a journalist, he is not so scientifically engaged. The role as journalist has its emphasis on the societal level, mostly inquiring in what other people think, without the ability to take measurements of radiation. The role is therefore not so scientifically engaging.

In Figure 7, some results from the questionnaire on the scientific content are shown.

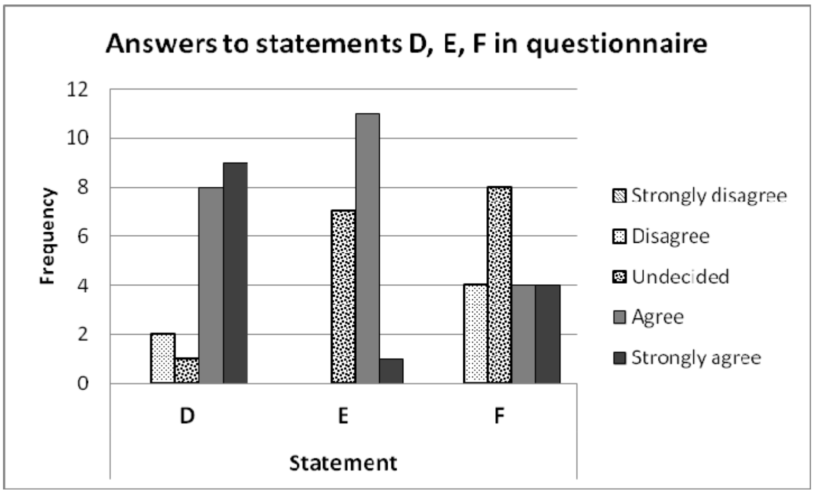

Figure 7. Frequency of answers to the following questions:
D: I felt I was working with science (n=20)
E: We used science language when discussing (n=19)
F: The game made me more interested in science studies (n=20)

Most of the students agree or strongly agree with statement D that the game made them feel like they were working with science. Three students who disagreed or were undecided had "non-scientific" roles as Project leader or Journalist. When asked about using scientific language in the discussions (statement E), students answer positively. Although these, and also other similar questions, show that the students experience the scientific content of the game, there is no clear tendency that the students express that they get more interested in science studies (statement F).

A deeper study on the students' uses of scientific concepts based on the second part of the intervention (the discussion) will be reported in a coming article.

Complex and Socially Significant Problem

One of the challenges met by the students was the unstructured and complex nature of the task. Osborn and Collins (2001, 450) put forward that students are used to a one-way communication in science classrooms, which makes them to be "frogmarched across the scientific landscape, from one feature to another". In Transformer, students have to find their own way, working with a multitude of variables affecting their actions and decisions.

> *Interviewer: What was most difficult in the game?*
> *Susanna: The hardest was to put everything together, because it felt like we'd received so much information from everybody, and then you had to check for example the board of environment, their rules, that is the radiation levels. We checked the power company and then we checked generally how high the levels were. There was somewhat different information everywhere, so it was difficult putting it all together, all the information from all those places.* (Technician)

Susanna's struggle with conflicting information from different sources, not knowing whom and what to trust is in fact a reaction to a major aim with SSI: to handle conflicting interests and evaluate information. Referring to a national study (OST/Wellcome 2000) Ratcliffe and Grace (2003) conclude that people tend to consider e.g. university scientists and scientists working for research charities as sources that are neutral and independent and therefore the most trustworthy. Likewise, politicians and newspapers are considered as the least trustworthy due to their vested interests. Susanna, in her role, dealt with information from WHO, SRSA (the Swedish Radiation Safety Authority), newspapers, and her own measurements and observations. In constructing an argument based on these sources of information, she had to critically evaluate their trustworthiness and apply her own science knowledge in order to decide the relevance of her own measurements. Her statement also reflects that in this SSI, the students worked on their own, outside the classroom, and without the influence of a teacher present to guide them. In *Establishing the Norms of Scientific Argumentation in Classrooms*, Driver, Newton, and Osborne (2000, 305) observe that "far from students being given opportunities to work their way through issues – in most classrooms, even those addressing socio-scientific issues, it is teachers who do the talking and structure the arguments". Susanna and her role mates were obliged to engage in thinking, discussion, and decision-making processes, without any explicit teacher guidance.

Figure 8 shows some results from the questionnaire. From statement G we can see that the students discussed a lot when collecting information. The complex nature of the case they studied forced them to make decisions on how to use and evaluate the information. The problem concerning different aspects of the building of a campus area and the possible health effects from the transformer station is complex. According to the answers to statement H, the students found the problem quite realistic, thanks to the presentation through the simulation. From statement I we can see that students have to make big efforts to evaluate the trustworthiness of the information, due to the access to a lot of different sources.

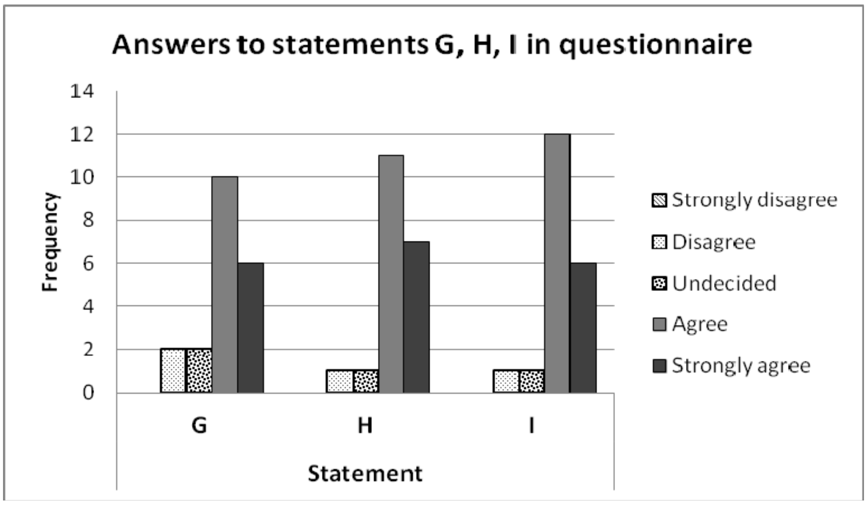

Figure 8. Frequency of answers to the following questions (n=20):
G: We discussed a lot in the group when we were collecting information
H: The game made the problem realistic
I: I made a big effort to evaluate the trustworthiness of the information we found

Discussion

The aim of this first phase of the design cycle was to design and evaluate the AR-game Transformer, using the theory of transformational play as a framework, and conduct a first intervention in a naturalistic setting. The results show that the combination of SSI and the augmented reality game platform was successful in placing the students as protagonists dealing with science content in a local meaningful context. The intervention gave students the opportunity to take part in peripheral participation (Brown 2006) in different communities of practice concerning a SSI about power lines and the dangers of electromagnetic fields. Due to the lack of affirmative evidence on the risks involved in living close to power lines and high-voltage installations, the students took an engaged and active part in the process of finding their own answers to the open-ended questions posed by the problem at stake. According to Sadler and Donnelly (2006), students can have some difficulties in seeing the science in an SSI, and especially using their school science in constructing an argument. Fleming concludes that:

> *Knowledge of the physical world is rarely, if ever, used when analysing and discussing socio-scientific issues. School science is the source of the colloquial expressions. It is not, from students' perspectives, a source of useful information for analysing socio-scientific issues.* (Fleming 1986, 696; quoted in Sadler & Donnelly 2006, 1481)

One of the main purposes of using SSI in science education is that "rather than simply being told about these socio-scientific issues, students should engage in an inquiry process that situates the course" (Barab *et al.* 2007, 59).

A closer look at the data gives a somewhat scattered picture of the students' experiences and impressions from the intervention. Clearly, the students identified themselves as playing a role in the simulation with elements of science in each role. They made connections to conceptual knowledge in science, which often is said to be the question at stake itself, since SSIs are based on societal issues and make students connect to societal knowledge rather than to science.

The nature of electromagnetic radiation, its dependence on the distance from the source, how it's measured, and how it affects people in the near surroundings of the transformer station, are vital facts to consider with connections to conceptual knowledge in science. Connections to procedural knowledge in science are more highlighted in the three roles with measuring capabilities. They plan and conduct measurements, value the results, and eventually renegotiate their plan. The three roles with measuring capabilities (Project leader, Technician and Engineer) report of discussions about how and where to take their measurements with different levels of logical substantiation. They also used their measurements in building their arguments. The other two roles, Chairman and Journalist, acted on a more societal level, with interviews as their main source of information. When analysing data from these two roles, we can notice a lack of challenges affecting these players' use of science concepts. The outdoor part of the intervention for them may have been too much of a treasure hunt, without complex group discussions about strategy and science. Social significance for the participants is generated by situating the game in their normal everyday environment, with the question at stake concerning their own health and well-being. These two elements, conceptual and/or procedural connections to science (Ratcliffe & Grace 2003), combined with social significance for the participants, can, according to Sadler, "*… serve as the basis for developing a different kind of community of practice in science classrooms"* (2009, 11). In this community of practice, the students formulated hypotheses about the impact of the transformer station. They collected and evaluated information to test their hypothesis and, after the outdoor part, assembled their evidence to an opinion representative of their role. By participating in Transformer, the students were encouraged to apply higher-order thinking skills, necessary to understand the complexity of different stakeholders' values in the game. Active participation in the role gave participants insights in the social practices of decision-making in a democratic society, which could be transferred to future involvement in similar processes outside school in "real life", more of *learning to be, than learning about* (c.f., Brown 2006).

From a pedagogical point of view, the modus operandi used in the design of Transformer presents several advantages, compared to other interventions using game-based tools and strategies. The augmented reality platform delivers the local context to the students, giving them tools to explore it, and at the same time it frames and restricts their actions to a specific area in space and time. This makes it possible to conduct the whole intervention in one school day, thus minimizing conflicts with other teachers and the schedule. The platform also gives the designer/teacher/team of teachers full control over which content to deliver to the students, and in which context the content will be situated. Using this control, the designers can constructively align the intervention with their own practice, and modify it to fit with their local needs and demands. This utility is in sharp contrast to many other games for learning, where students use expensive software developed to cover goals from the curriculum, but without any possibility for the teachers to align the content with their own practice. Lessons learned from this cycle will influence the next cycle in the research project.

Acknowledgments

We would like to thank Eric Klopfer and his associates at the MIT Teacher Education Program for both inspiration and technical support in the development of Transformer.

Thomas Lundblad is an acting high school science and mathematics teacher and since 2008 a member of the Swedish National Graduate School in Science, Technology, and Mathematics Education Research, FontD, at Linköping University.
Contact: thomas.lundblad@mah.se

Claes Malmberg is Ph.D. and senior lecturer in education at the faculty Learning and Society at Malmö University. His research focuses on socio-scientific issues and cultural perspectives on school science.
Contact: claes.malmberg@mah.se

Mats Areskoug is associate professor in physics, with emphasis on physics education. He has a special interest in environmental physics and the development of teaching methods, experiments and course books within the field.
Contact: mats.areskoug@mah.se

Per Jönsson holds a Ph.D. in physics from Lund University and is currently professor in applied mathematics at Malmö University. From 1995 to 1997, he was a postdoctoral research assistant in computer science at Vanderbilt University, USA. His research interests are in theoretical atomic physics, ecosystem analysis and technology supported learning.
Contact: per.jonsson@mah.se

References

BARAB, SASHA & KURT SQUIRE (2004). "Design-Based Research: Putting a Stake in the Ground." *Journal of the Learning Sciences* 13.1: 1–14.

BARAB, SASHA *et al*. (2007). "Relating Narrative, Inquiry, and Inscriptions: Supporting Consequential Play." *Journal of Science Education and Technology* 16.1: 59–82.

BARAB, SASHA, MELISSA GRESALFI & ADAM INGRAM-GOBLE (2010). "Transformational Play." *Educational Researcher* 39.7: 525–536.

BROWN, ANNE LESLIE (1992). "Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings." *The Journal of the Learning Sciences* 2.2: 141–178.

BROWN, JOHN SEELY (2006). "New Learning Environments for the 21st Century: Exploring the Edge." *Change* 38.5: 18–24.

COBB, PAUL *et al*. (2003). "Design Experiments in Educational Research." *Educational Researcher* 32.1: 9–13.

COLLINS, ALAN (1992). "Toward a Design Science of Education." *New Directions in Educational Technology*. Eds. E. Scanlon & T. O'Shea. New York: Springer-Verlag. 15–22.

COLLINS, ALAN, DIANA JOSEPH & KATERINE BIELACZYC (2004). "Design Research: Theoretical and Methodological Issues." *Journal of the Learning Sciences* 13.1: 15–42.

DESIGN-BASED RESEARCH COLLABORATIVE (2003). "Design-Based Research: An Emerging Paradigm for Educational Inquiry." *Educational Researcher* 32.1: 5–8.

Dillon, Justin & Jonathan Osborne (2008). "Science Education in Europe: Critical reflections." The Nuffield Foundation.
<http://www.nuffieldfoundation.org/filelibrary/pdf/sci_ed_in_europe_report_final.pdf> [2010-03-25]

Driver, Rosalind, Paul Newton & Jonathan Osborne (2000). "Establishing the Norms of Scientific Argumentation in Classrooms." *Science Education* 84.3: 287–312.

Edelson, Daniel C. (2002). "Design Research: What We Learn When We Engage in Design." *Journal of the Learning Sciences* 11.1: 105–121.

European Commission (2004). *Europe Needs More Scientists!* Brussels: European Commission, Directorate-General for Research, High Level Group on Human Resources for Science and Technology in Europe.
<http://ec.europa.eu/research/conferences/2004/sciprof/pdf/final_en.pdf> [2010-06-29]

Gravemeijer, Koeno & Paul Cobb (2006). "Design Research from a Learning Design Perspective." *Educational design research*. Eds. J. van den Akker, K. Gravemeijer, S. McKenney & N. Nieveen. London: Routledge. 17–51.

Gray, Donald S. & Tom Bryce (2006). "Socio-scientific Issues in Science Education: Implications for the Professional Development of Teachers." *Cambridge Journal of Education* 36.2: 171–192.

Kelly, Anthony E., Richard A. Lesh & John Y. Baek, eds. (2008). *Handbook of Design Research Methods in Education*. London: Routledge.

Klopfer, Eric (2008). *Augmented Learning*: *Research and Design of Mobile Educational Games*. Cambridge, Mass.: MIT Press.

Klopfer, Eric & Kurt Squire (2008). "Environmental Detectives: The Development of an Augmented Reality Platform for Environmental Simulations." *Educational Technology Research and Development* 56.2: 203–228.

Lave, Jean & Etienne Wenger (1991). *Situated Learning: Legitimate Peripheral Participation.* Cambridge: Cambridge Univ. Press.

Lundblad, Thomas *et al.* (Submitted). “Dialogic Manifestation of an Augmented Reality Simulation.”

McWilliam, Erica, Philip Poronik & Peter G. Taylor (2008). “Redesigning Science Pedagogy: Reversing the Flight from Science.” *Journal of Science Education and Technology* 17.3: 226–235.

Osborne, Jonathan & Sue Collins (2001). “Pupils’ Views of the Role and Value of the Science Curriculum: A Focus-Group Study.” *International Journal of Science Education* 23.5: 441–467.

Ratcliffe, Mary & Marcus Grace (2003). *Science Education for Citizenship: Teaching Socio-Scientific Issues.* Berkshire: McGrawHill Education.

Rosenbaum, Eric, Eric Klopfer & Judy Perry (2007). “On Location Learning: Authentic Applied Science with Networked Augmented Realities.” *Journal of Science Education and Technology* 16.1: 31–45.

Roth, Wolff-Michael & Stuart Lee (2004). “Science Education as/for Participation in the Community.” *Science Education* 88.2: 263–291.

Sadler, Troy D. (2004). “Informal Reasoning Regarding Socioscientific Issues: A Critical Review of Research.” *Journal of Research in Science Teaching* 41.5: 513–536.

Sadler, Troy D. & Lisa A. Donnelly (2006). “Socioscientific Argumentation: The Effects of Content Knowledge and Morality.” *International Journal of Science Education* 28.12: 1463–1488.

Sadler, Troy D. (2009). “Situated Learning in Science Education: Socio-Scientific Issues as Contexts for Practice.” *Studies in Science Education* 45.1: 1–42.

Sauvé, Louise *et al.* (2007). “Distinguishing between Games and Simulations: A Systematic Review.” *Educational Technology & Society* 10.3: 247–256.

Shaffer, David W. *et al.* (2005). *Video Games and the Future of Learning.* WCER working paper no. 2005-4 Wisconsin Center for Education Research. School of Education, University of Wisconsin-Madison, 1025 West Johnson Street Suite 785, Madison, WI 53706.

Shaffer, David W. (2006). “Epistemic Frames for Epistemic Games.” *Computers & Education* 46.3: 223–234.

Sjøberg, Svein & Camilla Schreiner (2005). “Students’ Perceptions of Science and Technology.” *Connect: UNESCO International Science, Technology & Environmental Education Newsletter* 30.1: 3–8.

Skolverket (2011). *Upper Secondary School: Natural Science Programme*. <http://www3.skolverket.se/ki03/front.aspx?sprak=EN&ar=1011&infotyp=15&skolform=21&id=14&extraId=0> [2011-04-10]

Squire, Kurt (2006). “From Content to Context: Videogames as Designed Experience.” *Educational Researcher* 35.8: 19.

Squire, Kurt & Eric Klopfer (2007). “Augmented Reality Simulations on Handheld Computers.” *Journal of the Learning Sciences* 16.3: 371–413.

SRSA [the Swedish Radiation Safety Authority] (2010a). *Magnetfält och hälsorisker* [Electromagnetic Fields and Health Risks]. <http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Broschyr/2009/Magnetfalt-och-halsorisker-low.pdf> [2010-06-23]

SRSA [the Swedish Radiation Safety Authority] (2010b). *Magnetfält* [Electromagnetic Fields]. <http://www.stralsakerhetsmyndigheten.se/Allmanhet/Magnetfalt--tradlos-teknik/Magnetfalt/> [2010-06-23]

WHO [World Health Organization] (2007). *Environmental Health Criteria 238: Extremely Low Frequency Fields.* <http://www.who.int/peh-emf/publications/Complet_DEC_2007.pdf> [2011-09-25]

WHO [World Health Organization] (2009). *Chapter 12. Health Risk Assessment.* <http://www.who.int/peh-emf/publications/Chapter%2012.pdf> [2010-06-23]