Exploring situated knowledge building using mobile augmented reality

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Abstract

Emergence of 'smart' mobile technologies has the potential to challenge our current understanding of digital tools and environments as a means for knowledge building. Within this framework, we have explored experiential and situated knowledge building that is contextualized across physical locations and digital environments by means of mobile augmented reality. We report from a design experiment in collaboration with a 9th grade science teacher in Oslo. The topic was set to be socio-scientific issues related to climate change, and we designed a mobile augmented reality application based on a 3D situated simulation including historical cues and open questions for the students to investigate. This environment was accessed from the school campus and on the proper location in the vicinity of the school. The findings show that students are able to connect observations in their physical and digital environments, knowledge building, and curricular subjects at several levels. We discuss the exploration in the context of emergent smart technologies that can facilitate higher-level outcomes such as more coherent explanations.

Keywords: Knowledge Building, Augmented Reality, Design Experiment, Out-of-School Learning

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Introduction

In educational research there is a focus on improving science learning by combining classroom activities with field trips in order to create variations and transitions between instructional contexts (Rennie, Feher, Dierking & Falk., 2003; Rennie, 2007). Learning experiences that are contextualized outside school are often termed 'informal', and designed as part of school-based learning (e.g., field trips to museums and science centres, outdoor learning spaces, etc.), have long been considered positive, enriching, educational activities that contribute to the achievement of scientific literacy (cf. National Curriculum in Norway). Opportunities for technological mediations have been investigated, and there are initial recommendations for the design of mobile technology to link learning across different contexts (Anastopoulou et al., 2008). Nevertheless, while the claims about the positive impact of the use of mobile technologies in different aspects of education are compelling, data regarding how these technologies support, for example, the understanding of complex concepts or the development of learning skills that enable students to think critically and problem-solve, are limited (Avraamidou, 2008).

Researchers have only recently begun to understand how learning experiences that cut across different contexts can foster deeper engagement for students, e.g., by opening up cross-disciplinary activities in schools and organizing observations and data gathering in the local vicinity of the school. We will avoid dichotomizing learning that happens in schools from informal learning that happens in out-of-school settings; instead we will distinguish learning in terms of how it is contextualized in and across various locations (Erstad, Gilje & Arnseth, 2013). The data presented in this article will explore how situated knowledge building among students using a specific mobile augmented reality application can create new experiences about subject content in schools.

The larger backdrop for the exploration in this article is the need to integrate 21st century competences into school practices and into existing subjects (Voogt & Roblin, 2012; Erstad, Amdam, Arnseth & Silseth, 2014). Integration is challenging both for teachers and schools as it implies fundamental changes both in terms of what is to be learnt and how (Voogt, Erstad, Dede & Mishra, 2013), as we don't have appropriate models for how 21st century skills are to be implemented in lesson plans and in assessment strategies, the teachers are not prepared, and there are no systematic and scaled strategy for innovation in teaching and learning. We explore 21st century competences as cross-disciplinary and integrated into existing subjects to emphasize deeper learning (Voogt & Roblin, 2012), e.g. through increased emphasis on critical thinking and problem solving, implying a focus on identification of relevant questions, having multiple problem-solving strategies, being able to analyse, evaluate, and describe statements, arguments, and proofs from different sources, and being able to act in unknown situations and contexts (Erstad et al., 2014).

We empirically explore knowledge building that is contextualized across physical locations and digital worlds by means of a digital learning ecology and mobile augmented reality. We investigate how this technology may connect locations, both physical and digital, with people and collective emergent ideas. Our research questions are: How do digital learning ecology and mobile augmented reality facilitate situated and collective knowledge building in general? and to what extent do higher-level outcomes, such as better explanations and more coherent understanding, emerge as this is at the core of 21st century competencies?

The article first reviews digital learning ecologies and knowledge building in the context of 21st century competencies, and then presents our design-based study, exploring the digital learning ecology and mobile augmented reality that merge real and virtual worlds in a knowledge building activity that took place in a 9th grade (age 14-15) science classroom and on a field trip (Liestøl, Smørdal & Erstad, 2015). We discuss and draw conclusions regarding the potential of digital learning ecologies and mobile augmented reality for the emergence of higher-level outcomes.

Digital learning ecologies and situated knowledge building

According to Barron (2004), learning ecology is defined as the set of contexts found in physical or virtual spaces that provide opportunities for learning. Later, Barron (2006) expands this notion to multiple settings as part of an individual's overall learning ecology, where each context is comprised of a unique configuration of activities, material resources, relationships, and the interactions that emerge from them. Building and sustaining learning ecologies can be challenging, as the ecology is entangled with teaching and learning practices, as it connects activities, material resources, relationships, and interactions at many levels. Kropf (2013) argues that the Internet has become a focal point for a potentially dynamic modern learning theory called connectivism (Siemens, 2005), as it is comprised of information reservoirs namely, online classrooms, social networks, and virtual reality (simulated communities) to expeditiously create, reproduce, share, and deliver information into the hands of educators and students. Saadatmand and Kumpulainen (2012) discuss connectivism as one basis for networked learning where social media and web technologies promote connections between the learner, human resources, content resources, and learning communities and continually dealing with ever-increasing amount of digital information.

Scardamalia and Bereiter (2003) describe knowledge building as a socio-cultural process that takes place in a community, emphasizing the importance of knowledge-creating competencies in a knowledge society, and also the need to work creatively with knowledge in the 21st century (Scardamalia & Bereiter, 2010). There are similarities to Papert's approach of constructionism in the sense that knowledge building is grounded in a tradition that emphasizes the learner's active participation in the learning process. However, Scardamalia and Bereiter (2010) place more emphasis on intentionality and on the collective purpose of knowledge building. A knowledge-building community aims at creating new products such as ideas, explanations, or theories that support members of the community in understanding their environment. The challenge of fostering knowledge building is not to control the self-organizing process as some instructional approaches attempt to do, but to facilitate the emergence of higher-level outcomes—e.g., better explanations and/or more coherent understanding (Scardamalia & Bereiter, 2014).

Cress and Kimmerle (2008) present a theoretical framework for describing how learning and collaborative knowledge building take place. They use Piaget's model of equilibration to explain how people take in new information from their environment, and how they perceive and encode this information from outside and integrate it into their prior knowledge. If information is new and not in line with existing knowledge, this causes cognitive conflict. There are two possibilities to solve a cognitive conflict; people can assimilate the new information or they can accommodate their knowledge (Cress & Kimmerle, 2008). The latter process is interesting in our case, as we explore situated and hybrid environments with incongruity between the physical and the digital. This may lead students to not simply assimilate new information into existing knowledge, but actually develop and build knowledge in order to better understand the environment.

The case: A design-based exploration of situated knowledge building

There is an urgent need for design-oriented study in this field as a majority of the existing studies have used mobile games embedded in previous generation technologies instead of tablets or smart phones, which seems to be the most recent trend in educational settings (Koutromanos & Avraamidou, 2014). The increasing presence of multiple sensors in mobile devices creates opportunities for completely new types of services, which may fundamentally influence many of our forms of expression and communication, including the domains of education and learning.

Design intervention: Using mobile augmented reality to hybridize the physical and the digital

We have adopted a situated simulation that is a collaborative 3D tool and virtual environment that takes advantage of the sensors for movement, positioning, and orientation. In a situated simulation there is an approximate identity between the users' visual perceptions of the physical environment of a given location and the users' visual perspectives into a 3D graphics environment as it is represented on the screen. The relative congruity between the real and the virtual perspectives is obtained by letting the camera position and movement in the 3D environment be conditioned by the positioning, movement, and orientation sensors. As the user moves in real space the perspective inside the 3D graphics environment changes accordingly (Liestøl & Morrison, 2013). A situated simulation is closely related to mixed and augmented reality. While mixed reality is characterized by different combinations of virtual and real representations along the reality-virtuality continuum (Milgram & Kishino, 1994), a situated simulation is a solution where there is a distinct (although minor) difference between the virtual (audio-visual) perspective via the device and the real perspective of the user in the physical world. This approach has also been labelled 'indirect augmented reality' (Wither, Tsai & Azuma, 2011). Yoon, Elinich, Wang, Steinmeier and Tucker (2012) have indicated that students demonstrated greater cognitive gains when augmented reality scaffolds were used in a museum exhibition setting. Compared to their experiment, we put more emphasis on situated and located activities.

For the experiment in question, the situated simulation platform was extended to include a set of new features not systematically evaluated earlier: the ability for the users/students to add, name, and position spatially distributed hypertext links inside the virtual environment (with corresponding 'real' spatiality); node modalities included written text, recorded audio, and photos taken with the camera on the device; a chat function for online communication among participants in the same group; and the possibility to comment on each other's posted links and chat messages. Avatars were also implemented so that students could view the identity and location of fellow members in the same group. These functionalities were added to support the student's ability to conduct real time digital documentation on location as well as communication to coordinate the activities in the group. All added and generated information was stored and accessed via a digital ecology.

Task intervention: Cross-curricular and situated knowledge building

The situated simulation in question, *Opera2222*, is a virtual reconstruction of the Oslo Opera House and its nearby environment in the year 2222 (Liestøl, Morrison & Stenarson, 2015). The city is in complete decay, re-vegetated, and looks abandoned with a new sea level more than two meters higher than it is today. In the application, the users can move around on the Opera House roof and explore the future environment.

Together with a teacher, we designed a pedagogical plan for using the app in a 9th grade science classroom and during a field trip to gather experience regarding new sets of constraints and potential capacities for connecting experiential and experimental knowledge building to curricular goals. On seven locations, we have implemented links with informational clues in the form of questions related to several of the traces or residual elements visible on the Opera House building itself or in the nearby environment—an uncommon plant, a flickering light in a distant building, a warning sign written in English, etc. The students were asked to find and explore each one, take notes, and otherwise document their reflections on the various 'story-building' elements as a basis for their upcoming presentation in the classroom where their assignment was to retell the story from present to 2222.

Figure 1. The *Opera2222* situated simulation in use on the Opera House roof in Oslo displaying the year 2222

Methods

The exploration took place in the autumn of 2014 and ran for a week. The investigation was divided into preparations in the classroom on the general topic of climate change (2 hours), field trip (1.5 hours), reconstruction of the possible history from present to 2222 (2 hours of unguided preparations), and finally a plenary presentations in the classroom (1 hour presentations, 5-10 minutes for each group).

The research data consists of video from the field trip and examples from students' documentation and communication activities on location and how these were reused and co-constructed in the group presentations.

The advantage of analysing the activity through video data is that one does not interrupt the process of learning and that one is able to analyse the flow of actions before and after interesting events take place to extract information on how the physical and digital environments, both regarded in isolation and as connected, may have influenced the interactions. The video data was collected using a handheld camera so that we could follow two selected students around on the roof. The students had a wireless microphone and were encouraged to think aloud while examining the environment. In this article, we follow one of these students, and our analysis of video recordings is based on the principles of interaction analysis (Jordan & Henderson, 1995), which emphasizes not only the dialogues among the participants, but also the patterns of interaction that involved nonverbal interaction, objects, and other material resources. We have selected three illustrative episodes from the video data. The first shows the initial encounter with *Opera2222* by a student, the second is a collective encounter, and the final shows a student group presenting the result of their knowledge building activity after the field visit in the classroom.

Analysis: Connected and situated knowledge building

Figure 2. Students explored the situated simulation on the Oslo Opera House roof, in collaboration and individually

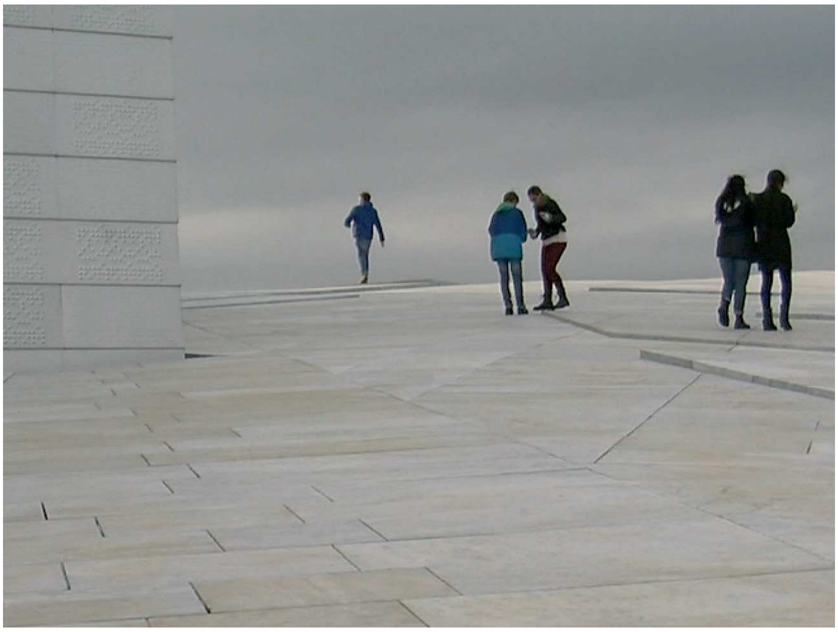
The student's first encounter with the environment

The teacher had organized the students into groups. The groups are instructed to work together, and each student gets a mobile phone with the app described above installed. The teacher explains the tasks, and one of the authors explains the basic function of the app. The students then take off to explore the environment. The student we are following first orients herself in the environment by carefully pointing the mobile phone in every direction and walking slowly in one direction. The student's starting point is near the current waterfront, but when activating the year 2222 mode in the simulation, her experience is that of being underwater due to the heavy rise of the sea level. She has to walk away from the waterfront to emerge from the future water level. The student is asking a lot of questions: "It's dirty here! What is that stone doing there?" Eventually postulations are made about the environment: "There is a wall between the water and the house. To restrict people to walk there!" And more overall: "Maybe there has been a war; it looks like somebody died here! It looks like nobody lives in 2222. Of course, nobody lives here, what happens in the world? The water is only dirty. No fish could live here."

Analysis

The student first connects the embodied experience with the experience in the virtual world. The clues in the world are noticed and generate questions about the artefacts in the virtual world. After a while, these artefacts are seen more in connection to each other and more overall theories about what has happened are formed.

Figure 3. Students met on the roof to exchange experiences and to make sure they have found all the information that is embedded in the environment



The students meeting on the roof

The students work in groups. They have access to a group chat on the app, but the first coordination among the group members happens as they unintentionally bump into each other on the roof:

Student 1: "One, two, three, four, is it one over there?"

Student 2: "We have to find seven! Which ones have you found; we miss one. Where did you find it?"

Student 1: "Did you answer all the questions?"

The prompts and the student's responses: Student reading from screen: "What does this tell about the future urban development policy in Oslo?"

Student 2: "It is only grass! It is two new buildings. The existing ones are dirty! [...] Yes, of course there was a war. Yes, we are extinct" (she walks away).

Figure 4. Screenshots showing activated clue information related to the dike (above), and user generated hypertext links (in green) named and placed in the virtual environment by participating students with a photo of the present environment showing the absence of the dike and lower sea level (below)

Analysis

The first social encounters are about coordinating the search for questions and clues, making sure they cover all of them. Some of the questions and clues are easy to find, while others are placed at locations that are not in plain sight. Eventually, the social interaction is more oriented toward the questions and a collective investigation into finding explanations. However, few students finalized explanations while on the field trip, but spent the time mainly on observation, exploring the environment, and making notes (both in writing and as recorded audio comments). They made sure they collect all the information. Analysis of the log of the chat function also shows that the students, when exploring the site individually and temporarily, lost track of each other and used the chat function to find each other and coordinate physical meetings to reunite as a group.

The topic of the presentation

The presentation that our student was part of lasted for five minutes, where everyone in the group had one topic to present. The central topic was naturally concerned with the various effects of climate change. The students presented clues related to the dirtiness of buildings and monuments, and that the air was grey. They explained this as more growth of bacteria. They explained the cause of global warming referring to the greenhouse effect and describing heating due to long radiation sunrays being reflected in the sky by the greenhouse gasses. This causes the icecaps on the poles to melt, which accounts for raise in sea level. They referred to dikes built in the sea to protect the city from the rising sea level. The change of flora and fauna is explained by an increase in temperature. They referred to a Poinsettia, a plant originally only found in Mexico and compared the climate in Mexico to that of Norway. They also referred to increased use of pesticides and more industrial waste, and its spread through rivers, as main reasons for changes in the flora. The new (taller than present) skyscrapers are explained by increased immigration, creation of more jobs, and the need for a larger labour force. They observed a flickering light source in a distant building and believed this was a fire or a large fireplace or a light from a solar panel.

Analysis

The clues and the questions in the environment gave structure to the presentation in terms of the topics they covered. They were able to discuss and find relevant information outside the environment in order to find explanations and to come up with theories. The students connected the experience on the roof with the topics from the curriculum and were able to make relevant connections between various disciplines, such as natural science and social studies. The teacher in this pilot study shares our evaluation. The experiment is very promising as a basis for continuing work in this field. There are two main observations. First, the students were able to make the situated simulation relevant for a deeper and cross-domain understanding of school subjects, and to a great extent, used sources outside the simulation to understand the background processes in terms of scientific and social theories. Second, the students came up with alternative ideas and explanations and used logic and likelihood reasoning to decide on causes and effects. The other observation is that the situated simulation fostered a rich experiential knowledge building opportunity, such as being immersed in water and walking around virtual objects.

Discussion

We will now address three aspects of knowledge building that we find of particular interest for our design-based exploration, as outlined in the review.

First, our primary concern was to recognize to what extent the technology promoted and supported students to connect; their perception and interpretations of the hybrid environment, and their collective inquiry across school subjects. The student we followed made connections between the physical urban landscape and the digital world that simulated climate change. This is not surprising, as this is an inherent feature of indirect augmented reality, as point-of-view, physical movements, gazes, and navigation are central, and also observed elsewhere (Liestøl & Morrison, 2013). However, there are many issues that need to be addressed when adopting this technology to educational contexts. One is the degree of similarity, or fidelity (see e.g. Lui, Macchiarella & Vincenzi, 2008) between the real and the virtual, and how correspondence between the two worlds may foster making connections. *Opera2222* is a confined space (the Opera roof) and has a corresponding elaborate 3D model. In our case students were familiar with the present surroundings, and could identify immediately with the consequences of climate change in the virtual world. We spent considerable effort to make a 3D model with both clear similarities, and some very noticeable incongruities, as a range of consequences needs to be predicted, designed visualized and animated. The effort required to make elaborate 3D models may hinder use of situated simulations in education. However, tools are becoming more accessible, and there is a potential for teachers and students to be involved in designing interesting environments.

Another issue is related to the level of diversity in the virtual world, as this may foster diversity also in the student modes of inquiry, such as exploration, sense making, and conceptual understanding. Based on the analysis, we would argue that the connections students are making are emerging, from the initial encounters with the situated simulation, to the student group presentations in the classroom. In this way, the contextual dimension of knowledge building became more apparent and became something they brought with them back to the classroom as part of preparing for their presentation. The students engaged in a knowledge building activity and connected many factors from several disciplines. The students used curricular resources from science, technology, and history, and they made social-scientific claims and turned the presentation into a compelling narrative. We suggest further research applying ideas from connectivism (Siemens, 2005; Kropf, 2013) to better understand the potential for emergence in knowledge building, as the students engaged in a process of connecting specialized information sources, and were able to see and nurture connections between fields, ideas, and concepts.

Second, we wanted to understand how situated simulations might promote collective and intentional activity. We observed that the *Opera2222* simulation shaped the student activity through the clues and questions that were located in the digital world. The inscribed clues and questions into the digital environment are of particular interest for us, as we want to understand how they shaped the learning activities, in terms of topics that were made relevant, timing, sequencing, roles taking, modes of working, and so on. The students made sure all the questions were visited, an activity that required them to coordinate their search and movements in the physical world. The questions are spatially organized, which also situates the students' perceptions both in the physical and the digital worlds. Collective and participatory activities were also observed as the students collaborated to validate idea development while walking within the physical space and at the same time, relating to the mobile augmented reality they carried with them. Our clues and questions were designed for a relatively short knowledge building activity (one week); inscriptions for longer and more diverse activities may need different designs. We integrated a chat in the mobile application. The idea was to support communication among group members. However, this function was merely used for coordination, and not used for knowledge building.

Further research is needed to better understand how situated knowledge building can be supported in situ, and how knowledge may be represented in a meaningful way on a mobile screen, and the potential for a digital ecology to foster knowledge building that is situated and emergent, and takes place at different locations and contextualized in and out of school.

Third, we designed a dystopia, as we wanted to understand how a hybrid environment with incongruity between the physical and the digital could trigger deeper engagement with the subject matter of climate change. We observed that the dystopic scenario combined with open questions triggered a great deal of wondering and generated several hypotheses about what had happened. Further, the scenario provided clues that triggered knowledge building based on accommodation (Cress & Kimmerle, 2008), rather than just assimilation. This was intentional, as the clues were diverse, surprising, and connected several fields, for example, the student's reference to war and large societal changes as a consequence of climate change.

Based on our findings, we argue that the highly connecting technologies, a digital learning ecology, and the augmented reality climate change simulation fostered a situated knowledge building activity that lead to better explanations and more coherent understandings among the students.

Concluding remarks

The broader implications of this project also relate to our conceptions of pedagogical context, in particular, related to 21st century skills. Context may become a key issue in the intersection between communities and schools, or between online and offline settings, as experienced by children and youth. The increased need of connection is also an argument for thinking about relationship between learning ecologies (Barron, 2006) and knowledge building activities. Based on classroom research, Barron then drew on multiple settings as part of an individual's overall learning ecology in her analysis of trajectories of computer use. Mobile applications, such as situated simulations, represent new possibilities of developing methods and content as ways that students move between school and community settings, and situated experiences in a virtual setting combined with physical presence beyond the traditional school field trip. The design challenge is to confront the students with exciting and demanding problems and ensuring that the higher purposes of the disciplines are not lost.

This research aims to contribute new understandings of situated and experiential knowledge building both by creating a virtual simulation of the situated experience with new sensory input and by supporting students as they move out from the school setting to another community setting in order to create deep personal engagement related to curriculum content.

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