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Students developing representational competence as producers with and of augmented reality in science

Abstract

This research aims to examine how augmented reality (AR) can be used in lower secondary science education. The focus is on outcomes as perceived by students and teachers from 3 rounds of piloting AR-resources, in the third round supporting students as producers of AR. Data sources are teacher interviews, questionnaires and video/observation from Danish, Norwegian and Spanish classrooms. Findings point to positive possibilities for supporting students' representational competencies, however dependent of the teachers' thorough use of scaffolding. Teachers refer to student learning of the science content through active engagement in technology-supported inquiry. Students report a high level of outcomes, e.g., by experiencing a sense of presence in the science phenomena and "seeing the invisible". The piloting with students as AR-producers in particular revealed affordances for their creative and collaborative use of digital resources (21st century skills), stimulating also dialogue about ICT from their everyday life as produced by someone.

INTRODUCTION

This paper presents findings from piloting augmented reality (AR) resources for lower secondary science education developed in a 3-year EU-ERASMUS project called ARsci, with participating schools from Denmark, Norway and Spain (more about the specific project in Nielsen, Brandt & Swensen, 2016). One of the aims of the project was to examine how school students can be supported in producing AR-animations and representations connected to their work in science.

The project adds to the increasing interest in the use of AR for educational purposes in contemporary research and development literature, both in a Scandinavian context (Maigaard, Lyk, Larsen, & Lyk, 2016) and internationally (Radu, 2014; Wu, Lee, Chang, & Liang, 2013). The use of AR in education must however still be seen as in its infancy, and further research are asked for to expand the knowledge about how meaningful learning can be mediated with AR (Radu, 2014).

BACKGROUND

The background section will start by referring to AR, seen in an educational context, and then continue to explain the theoretical framework for the present research, where AR is examined in a context of classroom dialogue and with a particular focus on students as producers, not just consumers, of ICT.

AR: adding virtual objects to the real environment

AR is defined by the combination of real and virtual objects in a real environment, running interactively and in real time (Azuma et al., 2001; Radu, 2014). Pokemon-go is an example from the popular culture, adding virtual objects to the real environment. This is an important distinction with respect to Virtual Reality (VR), where the user primarily relates to a virtual environment. AR and VR can be illustrated as a continuum, where reality-elements to a lesser or a greater degree are augmented, enhanced, enriched or diminished by computer-generated virtual elements (figure 1).

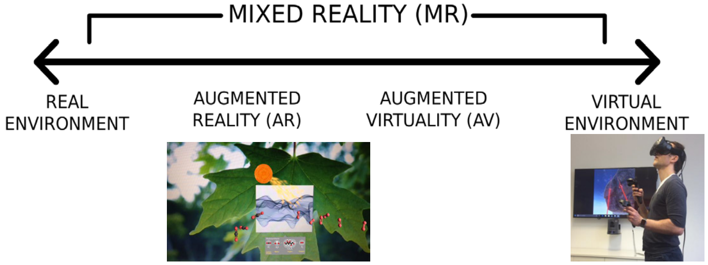

Figure 1. A continuum of mixed reality comparing augmented reality (AR) with virtual reality (VR). The photo illustrating AR is seen from the user's view with both reality and the added content (see also figure 2). The other photo is seen from outside illustrating a person using VR.

Smartphones and tablets are equipped with sensors such as camera, GPS, accelerometer and gyroscope allowing the smartphone to form a virtual perception of the real world and use this information to add a layer of augmented content. The AR content is often launched by letting the device read a visual marker placed in the real environment, but AR can also be marker-less using location data, such as GPS, to identify where the user is before overlaying pertinent information (Cheng & Tsai, 2013).

The example with the leaf in figure 1 and 2 illustrates one of the resources developed in the project where the user is looking at a leaf on a tree where an AR-marker is placed and through the tablet/smartphone seeing both the leaf and the invisible photosynthesis. This particular resource was part of a serious of AR-animations illustrating various models related to photosynthesis, water transport in roots and xylem etc. The task for the students was more than just looking at the models, they were the ones suggesting how and where the various representations could be placed at a tree in the real environment. More about the specific AR-resources below in the findings.

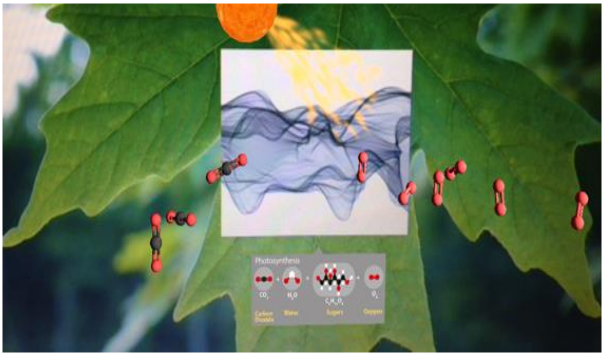

Figure 2. Example from the resource "Lost in the woods" showing a digital layer on top of a AR marker placed on a real leaf seen through the tablet/smartphone. Instructions of how to access this and other project resources are in the ARsci user-guide (link in references).

AR in education

International research on the use of AR in educational settings is as mentioned still in its infancy, but in Nielsen et al. (2016) we have summed up on some affordances and challenges based on the research literature so far referring among others to Radu (2014) and Wu et al. (2013). From an international review on AR in education Radu (2014) found benefits such as increased content understanding and student motivation, while challenges were about usability difficulties and ineffective classroom integration. Among the factors influencing student learning is in particular highlighted that the content can be represented in multiple ways, i.e., as sound, visualization and animation facilitating students' ability to experience phenomena that are otherwise impossible or infeasible, e.g., due to spatial scales. Wu et al. (2013) point to the following affordances: learning content in 3D perspective, ubiquitous, collaborative and situated learning, learners' sense of presence, immediacy, and immersion, visualizing the invisible and bridging formal and informal learning.

To further inform the understanding of AR as an element in science education in particular we will continue to the include research on ICT and the learning and teaching of science.

ICT in science education

Based on research in science education, learning opportunities are especially emphasised when students are working inquiry based in meaningful contexts using ICT for data collection and analysis, and in modelling the complex processes and phenomena (Krajcik & Mun, 2014; Hennessy et al., 2007). International comparative research has however shown that students are still predominately using ICT for seeking information on the internet, net based tests etc., the so called low level use of ICT (ITL Research 2011; ICILS, 2014). So, there is an identified need for developing innovative approaches supporting students' high-level use of ICT in education, e.g., with students working actively as producers, not just consumers: "*Being born in a digital era is not a sufficient condition for being able to use technologies in a critical, creative and informative way*" (ICILS, 2014: 5).

Students as producers in science denote activities like creating their own representations, multimedia productions and animations (Prain & Tytler, 2012), but also collecting and managing their own data with ICT. The need for students developing representational competencies for working with models, animations etc. is also referred to in the national science curricula in the participating countries. The project has used a generic conceptualization of representational competence slightly refined based on Waldrip and Prain (2012, p.146). Referring to this, students are expected to be able to: a) describe the codes and signifiers in a representation, b) explain the links between representation and the target concept or process, c) compare key features of the concept across representations, and d) point to key features to be emphasised when designing their own representations. In this context, "signifiers" means the visual representation of a given phenomenon, and "codes" the rules for the connection between them. The verbs in the description of learning outcomes (a-d) illustrate a progression from more simple demands (describe) to the more complex synthesis, where the students are able to recognise conceptual links across representations, and finally application, where students use their knowledge designing their own representations.

So, the major affordances of AR in lower secondary science can be hypothesized to be supporting students' use of AR closely connected to their active work with the science content, and potentially with the students themselves as (reflective) designers of AR-representations.

Students as designers is highlighted in a range of frameworks for 21st century learning. Such frameworks are widely used to illustrate the skills and knowledge students need in future work, life and citizenship referring among other things to critical thinking through problem solving, collaborative use of digital media, communicative skills and creativity in production and design (Larson & Miller, 2011; Voogt & Roblin, 2012). The various frameworks illustrating 21st century skills are with good reasons discussed questioning if this is new at all or basically about experience based learning and critical inquiry as described by Dewey. Going deeper into this discussion is beyond the scope of the present paper, but the important point is that across models of 21st century skills the need for teacher support is referred to, e.g., to qualify students in negotiating ideas with others (Larson & Miller, 2011). In the field of science education, Knain and Kolstø (2011) likewise refer to the teacher's role in supporting students' work with and reflection on data and models emphasising teacher scaffolding of students talking and discussing science as an essential part in inquiry based science education. And, in the specific field of students' work with representations and animations, Ainsworth (2008) discusses how animations can be very difficult for learners to perceive, they do not by themselves develop and apply effective strategies for learning with animations. Waldrip and Prain (2012), referring among others to Ainsworth, discuss the multimodal discourses in the science classroom in particular, and conclude that students need to be supported if effective conceptual understanding are to be achieved. Based on these arguments, we will continue with a specific focus on student dialogue and teacher scaffolding in the theoretical framework for the present research.

Student dialogue and teacher scaffolding

Student learning through classroom dialogue is examined in a range of research projects in particular referring to a social constructivist theory of learning (Barnes, 2009; Lefstein & Snell, 2014; Mercer, Hennessy & Warwick, 2017; Nystrand et al., 2003). Lefstein and Snell (2014) and Mercer et al. (2017) refer to various kinds of classroom talk, where exploratory talk is used to describe the dialogue indicating a learning process. This might include hesitant incomplete use of new concepts enabling the students to try out thoughts about phenomena engaging critically but constructively with each other's ideas. Opposite, disputational talk is individualized and characterized by disagreement, and cumulative talk is without the critical engagement in each other's ideas. Research in science education, as mentioned, points to student dialogue and argumentation as significant components in inquiry based approaches and emphasises the need for teacher scaffolding e.g., in demonstrating strategies for handling the problems involved (Kind, Kind, Hofstein, & Wilson, 2011; Knain & Kolstø, 2011).

Teacher scaffolding can be both macro- and micro-scaffolding (Prediger & Pöhler, 2015; Pollias, 2016); macro-scaffolding being the planned sequencing of activities and micro-scaffolding the strategies the teacher uses in dialogue, engaging student perspectives and asking questions (Pollias, 2016).

Summing up, there is a call for more research examining students' high-level use of ICT, being producers for example of their own representations and animations. And representing content in multiple ways is highlighted as one of the affordances when students are working with AR. It is however crucial to be aware of the complexity related to student learning with animations (here AR). So, interaction and dialogue in the classroom setting, among students and in particular with the teacher, can be seen as a key to gain an insight into student learning when working with AR in science, in particular the dialogue called exploratory talk emphasised in research as the dialogue indicating a learning process.

Aims and research questions

The aims of the present study are to examine how teachers can support students in developing representational competence, and in learning about the specific science content represented, when the students are using and producing AR. This leads to the research questions examined in the context of the ARsci project:

- What do students and teachers emphasise as possibilities, challenges and perceived outcomes from the piloting activities with AR in lower secondary science?
- How do the teachers support students' exploratory talk and their development of representational competence during the science activities where AR is an element?
- What particular outcomes are seen when the students are producing AR-animations and representations?

METHODOLOGY

The project operates with an iterative approach to design, testing, re-design and adaptation in both the development of the AR-resources and over time in the three phases of piloting (design based research: Barab & Squire, 2004). The main focus is as argued above on students as producers, but in the first round of piloting students tested showcase material developed by the ARsci-team (table 1). This was aimed for the project-team to use the experiences in framing the later phase of piloting where students were producers of AR-animations. The science content used in designing these first AR-resources, like photosynthesis (figure 2), was chosen based on an analysis of the science curricula from the three participating nations and informed by a survey at the initiation of the project (Nielsen et al., 2016). In the second round of piloting, the teachers were designing AR-animations with the same software as the students were going to use in the next phase. The software system Blippbuilder and the app Blippar were used (see the project userguide for more information).

The two first rounds of piloting included two classes from each country (n=73) and their teachers. The third round of piloting only included students and teachers from Denmark and Spain (n= 46). The reason for only piloting in two countries in third round was due to resources in the project. All participating students were from lower secondary, 7th and 8th grade, aged 13-15 years old.

Table 1. Three phases of piloting and the data collection

	Research focus	**Data collection**
Pilot 1 **Spring 2016**	Trying out showcase resources developed by the ARsci-team.	Pre- and post-interviews with teachers. Observation (Norway and Spain) and video (Denmark) of classroom activities. Student interviews during activities (Denmark).
Pilot 2 **Autumn 2016**	Teachers as producers of AR-resources.	Pre- and post-interviews with teachers. Observation (Norway and Spain) and video (Denmark) of classroom activities. Online questionnaire for students (Denmark, Norway and Spain).
Pilot 3 **Spring 2017**	Students as producers of AR-resources.	Pre- and post-interviews with teachers and online questionnaire for students (Denmark and Spain). Video of classroom activities, and interviews with students (Denmark).

Data collection and data analysis

Multiple types of data were collected as illustrated in table 1, including student questionnaires, interviews with students and teachers, and classroom observations using observation schemes and in some cases video, both full class and video/audio following dialogues in groups of students. The analysis of classroom video consisted of creating a timeline based on the full teaching session, transcribing dialogues verbatim and situating these dialogues at the timeline. Dialogues from video were analysed looking into: 1) elements of teachers' macro- and micro-scaffolding, 2) various kinds of dialogue, e.g., exploratory talk among students and with the teacher, and 3) indications of students' representational competence (Waldrip & Prain, 2012).

Semi-structured teacher interviews (Kvale & Brinkman, 2009) were made following the same basic interview guide translated to the three national languages. Pre-interviews were about teacher expectations, their preparation, and their pedagogical considerations. Post-interviews were about their experiences from the sessions, both referring to their interpretation of students' work and engagement, and their interpretation of possibilities and challenges pedagogically and with the AR. In post-interview with the Danish teachers the classroom video was used to mediate the reflections.

Interviews with the Danish students were video-recorded, they were made informally during the students' work with the AR materials. Questions were about, what they were doing and their interpretations of the activities. The interviews were analysed using inductive thematic analysis (Braun & Clarke, 2006), condensing the students' comments on the specific piloting activities and the science content worked with.

The student questionnaire used in pilot 2 and 3 was first developed in English and then translated to the national languages using the same online questionnaire system. It mainly contained closed likert-scale questions, but included also some open reflections to elaborate on the answers. Questions were about the students' perceived outcomes; AR as a learning resource; if and how they found the content and activities useful for their purpose and aligned with the rest of the teaching in this theme; how they collaborated with peers and their communication with the teacher; and if they found it different than normal in the science class. Finally, they were asked for suggestions for qualifying the material. After pilot 3, questions about designing augmented reality, their outcomes from this and how they felt prepared to do so were included. The students answered individually by launching the questionnaire from a link they got at the end of the piloting. They answered anonymously.

Data-analysis was frequency analysis and cross tabulations, comparing the three countries. A report with data from the full questionnaire was made after each round of piloting among other things used formatively to guide the project development. The result section in this paper only include a few of the items from the questionnaires.

RESULTS

Results from pilot 1, 2 and 3 (see table 1) are presented separately, each with a short first discussion. An overall discussion summing up referring to the three research questions follows in the next section.

Findings from pilot 1

In the first round of piloting, teachers and students from Norway, Spain and Denmark were trying out two examples of pre-produced AR materials "Lost in the woods and "Catalytic converter" (detailed description of the materials in the ARsci user-guide). We present here only data from the Danish classrooms to be able to present specific dialogues. Findings from the next rounds of piloting will include also data from the other countries.

The two Danish 7th grade classes of respectively Physics/Chemistry and Biology were working with these two AR-resources exploring chemical reactions in a car's catalytic converter (figure 3) and processes related to photosynthesis (figure 2). Results from this part of pilot 1 are also discussed in Nielsen et al. (2017).

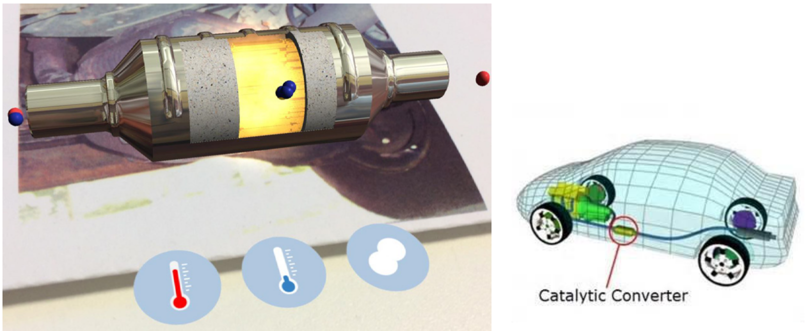

Figure 3. Example from the AR-resource "catalytic converter" with a 3D-model illustrating chemical reactions at micro level. The picture to the right was used to illustrate the catalytic converter placed on a car. The marker used to launch the AR was a picture of the convertor.

Catalytic converter

The teacher referred in the pre-interview before piloting to the expectation that AR could help students creating pictures of things they normally did not see, e.g., discussing substance conservation and seeing that these chemical reactions depend on certain things like heat. He reflected on the pedagogical thinking, that it is interesting for students to experiment themselves and to have the chance to see that things they meet in physics and chemistry deals with real-life processes (situated learning).

Based on analysis of the video from the piloting, three main phases were identified. First there were some open inquiries where students organized in groups tried out the AR-resource. The class had before worked shortly with the subject matter related to the theme. This was followed by a phase where the teacher was moving from group to group, helping, guiding and asking questions. After this followed more focused work with the AR-resource in the student groups.

During the first open inquiries students were engaged and fascinated, but commented in particular on the technical possibilities trying out features in this AR-resource like changing temperature:

Student 1: *Wauw this is cool*
Student 2: *What are these*
Student 1: *It is hot in there*
Student 3*: Okay you can see what is inside*

These dialogues are about questions like: What can this app do? What happens if…? The students refer to one of the main AR affordances of visualizing the invisible as described by Wu et al. (2013) when referring to what is inside. When interviewed they also emphasise this as catching their interest (more below).

In the next phase the teacher was moving around in class guiding the students practically, in connecting the AR-animation to molecular models, and in relation to thinking in substance conservation:

Teacher to a student coming up to the main table: *Now there is coming some oxygen and there is carbon dioxide* [..] *try to guess what it is* [..] *take it down to the group and explore*

Student: *Hey look-you can press on those small signs*
Teacher: *Yes, there you can activate or de-activate stuff*
Teacher at another group working at a laboratory table: *You need to look at what comes in and what goes out*
Student 1: *There is some carbon dioxide and there …oh what is it called.*
Teacher: *You can see if it is the same*
Student 2: *There is both a black and a red*
Student 3: *It is carbon dioxide and oxygen*

These dialogues show examples of micro-scaffolding (Pollias, 2016), where the teacher is supporting the students in using the science concepts, e.g., names on the molecules, and asking questions to stimulate reflections about substance conservation.

The students continued working in the groups. In the dialogue, there are examples where they refer to codes and signifiers (Waldrip & Prain, 2012) in the model in utterances like *"Try to look there* [..] *carbon dioxide"*. Neither teacher nor students do however talk about the animation as a model. In a third group of students one of the students in continuing to look at other things, including her pencil, through the app. She calls for the teacher and asks: *"How come that you cannot do the same with for example your pencil ..that you cannot look inside that".*

In the dialogues, students are building on each other's utterances about the signifiers in the model, some of them students were interviewed while working:

Student 1: You really learn a lot
Student 2: I did not imagine it to look like this…
Student 1: Yes, we can watch it from inside

The teacher after the piloting felt that the aims were reached: "*They understand the main points [..] reactions where heat is essential*". He experienced that the students quickly examined the possibilities provided by the given technology, but he would like an alignment to combustion processes in general, he suggested to expand the AR to include this. He furthermore suggested to use a 3D model as a marker, or an old car turned around, not just a flat picture (figure 3). He referred to the pencil question as "*a damned good question*" indicating implicitly according to him that the students were motivated to continue to work as producers with the technology.

Summing up, the analyses revealed opportunities for supporting students' representational competence in particular with the teacher's thorough use of micro-scaffolding with open questions and ongoing guidance. Students refer positively to "*seeing the invisible*", and the teacher also experienced positive outcomes. Based on the multiple data it seems that students develop to emphasise signifiers in the representation. They do however not refer explicitly to this as a model. Nor does the teacher. We know from research in science education that students typically have naïve conceptions of a model as a physical copy of reality (Grosslight et al.,1991), like some of the students above, so there appears to be a need for more scaffolding concerning the character of models.

Lost in the woods

Piloting the resource "Lost in the woods", a 7th grade biology-class was involved in model based inquiry exploring a range of different AR models and their ability to help them explain the basic function of a tree (one example in figure 2). The students after their initial work in class moved to the outside environment, where they physically placed the AR-markers on different parts of a tree. The last step was that they had to present for the rest of the class. Most of the students found this to be a motivating and engaging task. One student for example said: "*You see it all more real, it is meaningful, and you get a sense of how it is happening*". When asked to elaborate about the specific task of finding out what processes the various models represent another student said: "*I think it is fun [..] it would have been too boring and easy if she* [the teacher] *had explained about the models before we started, it is fun to examine it yourself*". But a few students experienced it to be a difficult task, one student used the term "*confusing*" answering the same question about the task of finding out what the models represent.

The teacher emphasised the possibilities for visualizing things that cannot be seen when reflecting about the affordances. She mentioned that the opposite approach - finding out what the models represent in stead of just using the models - forced the students out of their comfort-zone. Her impression was, that most of the students quickly understood and enjoyed exploiting the possibilities in the given technology.

Referring back to the design based research approach these experiences from the first piloting were used in adapting the materials, for example possibilities for using "Lost in the woods" in differentiated ways with various degrees of teacher guiding are now described in the ARsci user guide and discussed in Nielsen et al. (2017).

Findings from pilot 2

Findings from pilot 2 will be presented rather condensed to leave room to explore in more details the third piloting referring to the last research question.

Four different AR-resources were produced by teachers using the program Blippbuilder. It was tried in their classes with students using the app Blippar. The teachers in all countries produced AR closely connected to the science content they were teaching visualizing a magnetic field, rocks and plate tectonics and processes related to carbohydrates. These AR-resources and how they can be used in teaching science are all described in the ARsci user-guide.

The students in all three countries reported a high level of perceived outcomes in the questionnaire, for example did around 80 % of the students report that the AR-app to a high or a very high degree helped them acquire new knowledge about the science content they were working with (figure 4).

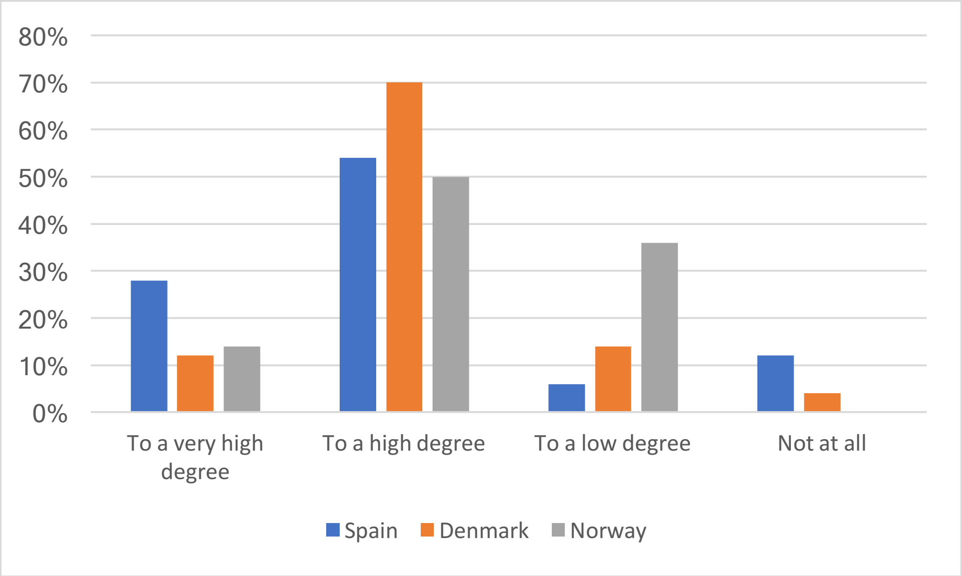

Figure 4. Students' answers to the question: "To what degree did the app help you acquire new knowledge on the science subject matter you were working with" in the questionnaire distributed after the second piloting. The representation is based on answers from 73 students.

The video from the piloting revealed examples of students' exploratory talk about the science content when working with the AR. But it was also evident from the video material that some students were distracted inquiring into other stuff that can be seen on the screen when using Blippar, exemplified with this quote from a student group (when the teacher was not present): "*..hey look it can recognize that there is gas under the table ..*". A particular issue in the data from pilot 2 with the teacher produced AR was that some of the students expressed an expectation for the resources to be of a high technical quality like the ones from pilot 1. In particular did the Danish students working with the resource "Magnetic field" designed by their teacher mention that the coil was not identical to the one they used in the real experiment with electrical transformation.

So, the students were surely engaged working with the AR like in pilot 1. But, though the teachers were producers of the AR used in class, the students were still just consumers of the technology, and their utterances indicated that they expected the same quality as in the ICT they meet and consume in their everyday life. And in general, the teacher-produced materials were referring to rather traditional science experiments like the one with electrical transformation. With reference to research talking about students' high-level use of ICT and students as producers in science this led to some discussion in the project group. Though the AR in pilot 1, like "Lost in the woods", was pre-produced, there were elements in the pedagogical design of the task with more degrees of freedom than in pilot 2. But the teacher scaffolding was concluded to be determent in both pilot 1 and 2. These considerations raised our expectations for the third piloting, where students were going to produce their own AR using Blippbuilder. Here the challenge for the teachers was not technical but pedagogical, e.g., related to micro- and macro-scaffolding (Pollias, 2016), shown to be so important.

Findings from pilot 3

In the last round of piloting students from 7th and 8th grade classes in Denmark and Spain designed AR-animations connected to a wide range of science themes. The piloting included a variation in student-tasks, e.g., level of openness and teacher guiding, referring back to the experiences and discussions from the two first rounds of piloting. Danish students worked with 1) an augmented world map, 2) developing representations of various elements of the global water cycle, and 3) illustrating electric circuits in the home and connecting it to the ones they worked with in the science lab. Students from Spain continued the work with geological models, rocks and fossils initiated by the teachers in pilot 2. All these examples are described in the ARsci user-guide.

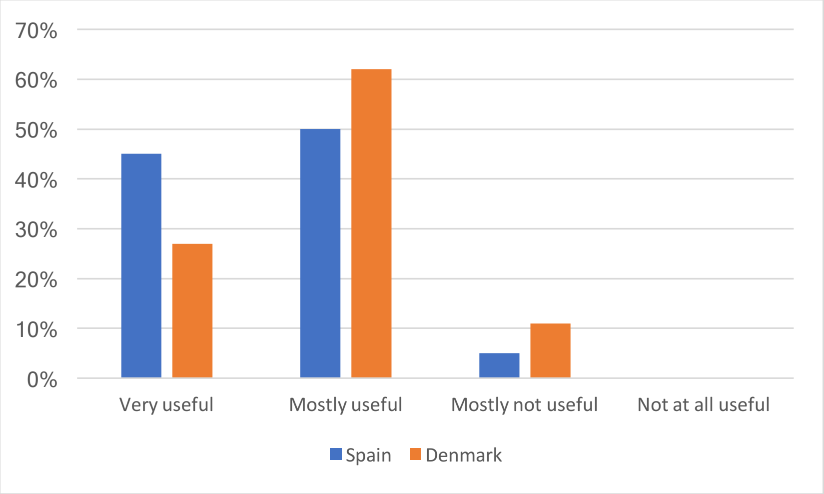

Figure 5. Students' answers to the question:" To what degree did you find the content and the activities useful for their purpose?" in the questionnaire distributed after pilot 3 (n=46). The content and purpose varied as described, but it was in each class made clear for the students what the question referred to.

The students also in this round of piloting reported a high level of perceived outcomes. For example, 90% of the students reported the activities to be very or mostly useful for the purpose (figure 5). There were however differences in the students' reflections compared to pilot 2, they for example referred to the possibility to be creative designing themselves. More about this below, but first some examples of the AR-resources.

In the project with the water cycle, the Danish students worked in groups to produce AR-animations modelling various processes illustrated in overview in figure 6. The water cycle is a complicated and abstract phenomenon consisting of many processes invisible to the naked eye, and these processes must be put together to understand how water is transported between the reservoirs. The aim was that the students by creating their own AR-animations could explore, understand and explain the various processes and phenomena. A large poster (figure 6) was made to support the students' understanding and to connect the resources made by the various student groups to a shared class project. However, the link to the real world is also an important element. The appertaining printed markers from the group projects can be placed on the poster with attention to the learners' discussion of correlations. The markers can also be placed in relation to concrete areas in nature with attention to the learners' link between model/representation and reality.

Figure 6. Model of the water cycle used to frame the collaborative work in pilot 3 in the Danish 8th grade class.

The 8th graders involved in the water cycle project had already been working with the design software Blippbuilder in a more structured first project where the class together produced an augmented world map. A video-interview with students describing this specific task and their experiences as AR designers is published in the ARsci user-guide (therefore we have used more space here to describe the later project with the water cycle). In the interview, the students among other things referred to Blippbuilder. Students and teachers have across countries reported some challenges related to the design technology in this software, but in the interview the students emphasised positively the possibility to work with 3D in the program, one of them for example stating " .. *it is worth the effort"*. In relation to the water cycle task the students emphasised that they themselves made decisions about the specific focus, and that they had to work creatively to design animations. Each group had a specific task like: "Design a model to illustrate processes related to a groundwater reservoir e.g., infiltration through various types of materials" or "Design a model illustrating some of the challenges related to groundwater as drinking water, e.g., pollution, pesticides, fertilizers".

So, the students valued the degrees of freedom in this task, the possibility to make their own decisions, but as mentioned they also highlighted learning outcomes from the first more structured task with the augmented world map. It seems to have been reasonable to start with a quite structured task when the students had to learn to use the new software, but then afterwards to move on to a more open task to stimulate further their motivation.

Another interesting issue is that the students during interview in pilot 3 emphasised a new respect for the teachers' design in pilot 2, e.g., the task with the magnetic field, with reflections about realizing that "*.. it can be difficult to be the one designing the ICT*".

DISCUSSION

In relation to the question about what students and teachers highlight as possibilities, challenges and perceived outcomes from the piloting activities, it is evident that students really liked being able to look into the science phenomena, seeing the invisible, working with 3D etc. as also emphasised by Wu et al., (2013). The students used terms like "*meaningful*" and "*get a sense of what happens*" when reflecting about the content and their experiences.

The teachers reflected on starting from students' open playful approach to the new technology and then moving on to a more focused science inquiry scaffolded by the teacher's questioning. This micro-scaffolding (Pollias, 2016) was also seen when analysing the video (for example the dialogues from pilot 1 above). In general, the teachers were positive in relation to students' learning outcomes. The teachers among other things noticed, that students are quick to exploit the possibilities when meeting a new technology, but also that the technology helped the students to understand some of the science content.

The AR examples appeared to provide meaningful contexts for the ICT integration in the science teaching (cf. Hennessy et al., 2007; Osborne & Hennessy, 2006). It can however be discussed to what degree the students were working inquiry based (Knain & Kolstø, 2011; Krajcik & Mun, 2014). In relation to a continuum from teacher-guided inquiry towards more degrees of freedom in problem, method or results (Knain & Kolstø, 2011) the first piloting showed that the open tasks could be too difficult to handle for some of the students though perceived as motivating for the main part of them. Furthermore, we saw that the teachers had a tendency to think in rather traditional science experiments when they were producers, maybe due to being unfamiliar with the technique. Referring to these first findings the possibility for differentiation in degree of openness when using a particular resource was developed along the project, and is now described in the user-guide. The possibility for the students to work collaboratively modelling the complex processes and phenomena in science (Krajcik & Mun, 2014; Hennessy et al., 2007) has in particular been exploited in the third round of piloting.

In relation to the research question about exploratory talk and students' development of representational competence, analyses have illustrated how students' exploratory talk was mediated by their experiments with the AR. The dialogues however also illustrate the importance of the teachers micro-scaffolding. But, based on the observations there are no examples where the AR-animations are explicitly discussed as models by students and teachers, and students do in instances talk about models as if it was a picture of reality. So, a need for extended scaffolding related to the character of a model can be highlighted. Teacher and students need to discuss and compare various kinds of models.

Students' development of representational competencies (see the conceptualization a-d of representational competencies above referring to Waldrip & Prain, 2012) is illustrated in examples from dialogues where they come to describe the codes and signifiers in the representations (a). There are also examples where the students explain the links between representation and the target concept or process while working with the AR (b), e.g. when the 7th graders are comparing with molecule-models. In relation to comparing key features of the concept across representations (c), this for example was seen when the students were producing AR themselves in pilot 3, working with and discussing various models related to the water cycle. These are some of the particular outcomes seen when the students were producing AR-animations and representations (research question 3).

We did however not see many examples where the students explicitly described key features to be emphasised when designing their own AR-representations (d in the conceptualization of representational competencies). The Spanish students did work with a kind of storyboarding, where they described their AR-design and the flow in it in details before starting. But the general character of a model, mentioned above, could have been discussed to support the students awareness of key features in various models when planning their designs.

The Danish teachers elaborated in interviews on their choice of not urging the students to start their design from storyboarding because they found, that the students have to know both the technology and the science process in depth before being able to take deliberate choices of key features. They emphasised this as a next step. But, they also experienced that students could actually start the first work with Blippbuilder after just a very short introduction. So, training the technology-skills does not necessarily have to take a lot of time from the work with the science content, but of course the practical technical work when working with new technology, like here AR, can take students' focus away from the science content. It is also illustrated in findings from pilot 2, that students can be distracted by the many possibilities in the technology.

Summing up, it can in a teaching context be meaningful to see both the students' development of representational competencies and their development towards working with more degrees of freedom when designing animations of science phenomena with the AR-tools as a progression. Such a progression is illustrated in figure 7 using a relatively simple electrical circuit AR-task from pilot 3 as an example.

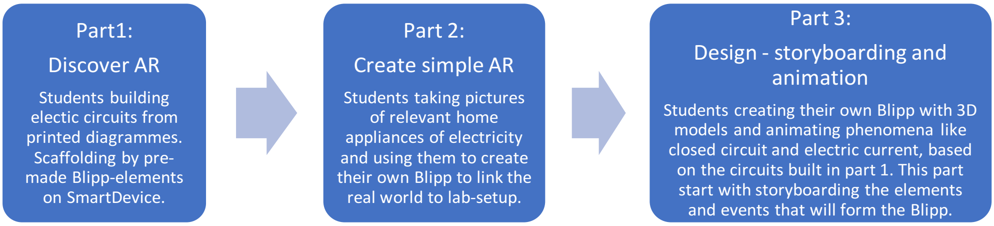

Figure 7. An example from the ARsci user-guide of a progression in the work with AR. The electrical circuit AR-task was developed to and tried in a 7th grade class in Denmark.

We will not describe this particular task (figure 7) in details, this can be found in the user-guide. The point of bringing the example into the discussion is, that this progression was described to acknowledge the teachers' positive experiences from letting the students work first as consumers, then with a simple AR-design, and then adding storyboarding in part 3.

In relation to particular outcomes from pilot 3 it is furthermore interesting that both the collaborative and creative production of AR referred to by the students, and the critical awareness of the ICT they consume in their daily lives as designed by someone, can be seen as central elements in relation to the models for 21th century skills (Voogt & Roblin, 2012). The latter is in the data for example indicated by the fact that the students' comments about their teachers as producers of AR changed in retrospective when they had themselves been working with designing AR.

Another issue, not directly asked for in the research questions, but referred to in the background literature, is the specific nature of AR merging the virtual elements with the surrounding reality (figure 1). We have in the ARsci project group in retrospective discussed, that possibilities for using the nature as a learning space with AR could have been more fully exploited. It was a focus in for example "Lost in the woods", and as described it was also suggested to be a focus using the big model in figure 6, that could also be used in the outside environment. But overall, students have mainly worked in the classroom or the science lab and not so much in the outside environment. To say it with other words, we have maybe in the project worked more with "augmented" than with "reality". The teacher-produced resource showing the magnetic field inducted in a coil was for example used with the laboratory equipment as the “reality element”. The next step could have been the connection to examples of electric transformation in the surrounding society. The connection between lab equipment and everyday life is however targeted in the task about electric circuits (figure 7). Anyway, looking forward, this field deserves to be further exploited.

CONCLUSION

Summing up, the piloting of AR-resources showed positive possibilities for supporting students’ exploratory talk and their meaning making related to the science content, however dependent of the teachers’ thorough use of micro-scaffolding. It is an important challenge to draw students’ attention to the character of a model as a representation with certain codes and signifiers. In general teachers were positive in relation to students’ learning outcomes, and students reported a high level of perceived outcomes, e.g., experiencing a sense of presence in the science phenomena and that they were able to “see the invisible”.

The third round of piloting where students were themselves producing AR-animations and representations in particular revealed affordances for their creative and collaborative use of these digital resources. This stimulated student dialogue about ICT from their everyday life as produced by someone.

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