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# Augmented Reality in science education – affordances for student learning

## Abstract

*Most extant studies examining augmented reality (AR) have focused on the technology itself. This paper presents findings addressing the issue of AR for educational purposes based on a sequential survey distributed to 35 expert science teachers, ICT designers and science education researchers from four countries. There was consensus among experts in relation to a focus on 'learning before technology', and they in particular supplemented affordances identified in literature with perspectives related to interactivity, a creator perspective and inquiry based science. Expert reflections were condensed into innovative dimensions in a framework with nine continua. The framework can be used to illustrate how, and to what extent, an innovative educational perspective, such as that focusing on engaging learners in creating and/or inquiring can be addressed in a particular AR design, and is in the paper exemplified for use in both analysis of existing educational AR and in design of new second-generation AR.*

## INTRODUCTION

This paper presents findings related to augmented reality (AR) for educational purposes, more specifically for Science Education in lower secondary school. When reviewing research in the field, several researchers emphasize the importance of focusing on the ways that AR technologies can support meaningful learning more than the technologies themselves, acknowledging that the use of AR in educa-

tion is still in its infancy (FitzGerald et al., 2013; Wu, Lee, Chang, & Liang, 2013). In their work, Wu et al. (2013) refer to three groups of potential stakeholders when developing AR for education: teachers/educators, researchers and ICT-designers. AR in education must necessarily be guided by usefulness for teachers and students in the process of teaching and learning core ideas and practices in science (Krajcik & Mun, 2014). However, designing technology to promote learning might best be qualified by merging the perspectives of teachers with those of other stakeholder groups (Wu et al., 2013).

The aim is to develop a framework for designing and analysing AR in science education based on rich qualitative data provided by expert teachers, researchers and designers from Denmark, Norway, the UK and Spain. Findings are yielded by the primary stage of an international EU-funded project (Fig. 1).

So - the framework is targeting a generic need to categorize and analyse various approaches to educational AR. In the specific project context the overall innovative approach informed by research in science education is that teachers and students are going to be AR producers themselves (Fig. 1), and the framework is going to be used to guide their design and analysis.

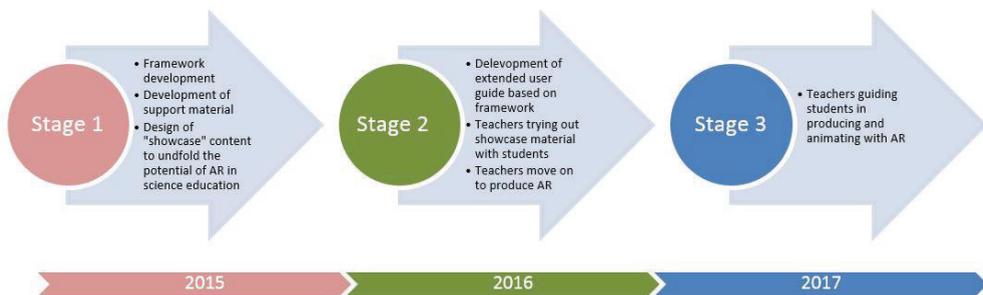


Fig. 1. Three stages in an international project 2015-17 developing AR for science education, and focusing on how teachers and students can be AR producers, <http://ar-sci.jorum.ac.uk>.

## BACKGROUND

### What is Augmented Reality?

AR is about augmenting/modifying user's perception of the real world. While some researchers define AR as a technical concept, others offer a broader definition. Azuma et al. (2001) define AR based on the following three properties:

- combines real and virtual objects in a real environment
- runs interactively, and in real time
- aligns real and virtual objects with each other.

This definition emphasizes the real environment as the place where virtual objects are added. This is an important distinction with respect to Virtual Reality (VR), where the user primarily relates to a virtual environment. Nonetheless, the two might best be seen on a continuum, whereby AR and VR represent a sliding scale of mixed reality, describing AR as real-time views of a physical, real-world environment. In this reality-elements have been (to a lesser or a greater degree) augmented, enhanced, enriched or diminished by computer-generated sensory input, e.g., sound or graphics as a layer or projection (Munnelly et al., 2012).

Klopper and Sheldon (2010) use a slightly broader definition examining learning in real-world contexts that are lightly augmented using digital information from mobile devices like cell phones, e.g. augmentation of the experience of being in a specific location not necessarily including visual superpositioning of virtual information.

### ***AR technology***

Technology used to display augmented content as a layer superimposed on the real environment can be divided into three categories, (1) mobile devices, such as Smartphone and tablet, (2) stationary units and (3) head mounted display (Azuma et al., 2001). Head mounted displays are rarely used in education as the technology is still expensive and immature. In contrast, many students nowadays bring smartphones to school. By harnessing the potential of a 'bring your own device' principle school's can increase access to AR devices. Furthermore, today's Smartphones, in addition to camera and microphone, have access to many other sensors, such as GPS, compass, accelerometer and gyroscope, i.e. tools to create rather sophisticated AR. And presently, resources for incorporating AR content into mobile devices are readily available from many vendors, i.e. Layar, Wikitude Studio, Aurasma Studio and Junaio browser. Thus, in the design of new AR applications in the project (see an example at the end of the paper), we like Klopper and Sheldon (2010) focus on mobile devices in particular, but the framework will be equally relevant for other types of devices.

### ***Categorization of AR applications***

Augmented Reality is often divided into marker-less or marker-based categories (Pence, 2010). Marker-less AR uses location data, such as GPS, to identify where the user is before overlaying pertinent information. Marker-based AR, on the other hand, relies on visual markers, such as QR codes. Cheng and Tsai (2013) supplement these two categories when differentiating between location-based and image-based AR. Location-based AR is typically marker-less, whereas image-based AR is using pictures as markers—rendered possible by the latest developments in the image recognition technology. These divisions are for now helpful when designing and developing AR resources. However, as technology is rapidly evolving, future devices will have a greater number of more sophisticated sensors for understanding the real world where overlaid content is to be presented, causing the number of categories to be extended accordingly, or may make this kind of division superfluous.

Two examples of first-generation educational AR are presented in the text boxes. The AR app 'The human respiration system' is a marker-based application using a hand-held device to scan the marker on the T-shirt. The 'Sandbox' is an example of a marker-less AR design using a projection display. We call these examples 'first-generation', as affordances for interactivity, data-driven experiments, etc. discussed below are not explicitly exploited. Nonetheless, the two examples provide the reader with a solid understanding of what educational AR might be.

### The human respiration system

As part of a pilot study an AR app was developed in 2013 to investigate how and to what extent students gained a better understanding through an increased focus on contextualized visualization. The setting was an anatomy course with 30 1st-year undergraduates at a school of nursing. This first generation AR app allowed students to visualize the workings of a set of lungs situated 'inside' a student's body using marker-based AR and handheld display (iPad). A marker placed on a T-shirt launched a 3D-model of a set of lungs expanding and contracting to simulate inhalation and exhalation (Fig. 2). By orienting the iPad, the 3D model could be viewed from different angles, while also allowing students to zoom in and out. In groups of 4-5, the students worked with the lung model, guided by the questions inspired by an inquiry-based science education approach (IBSE).



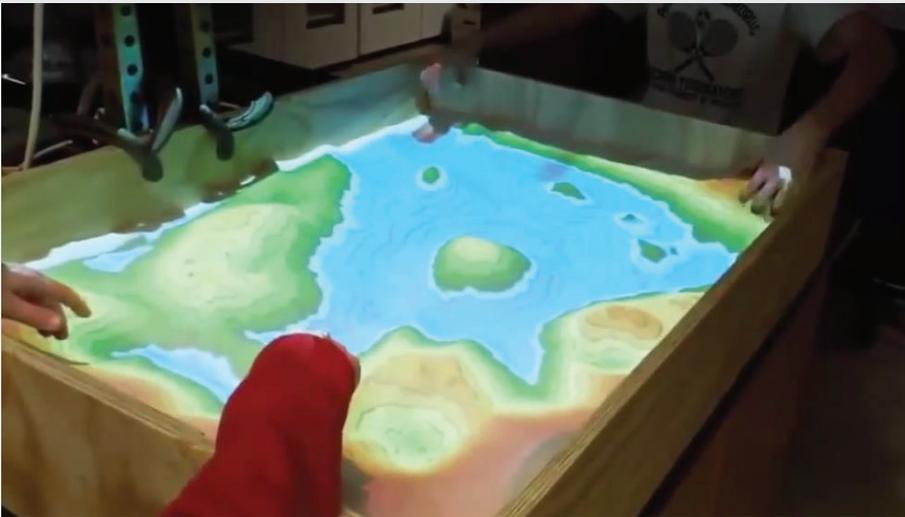
*Fig. 2. Student nurses examining human respiration with a marker-based AR application*

In contrast to the previously used visualizations, e.g. pictures, videos, and models, the AR app helped the participating nursing students in creating a realistic visualization of parts of the body in situ. In the pilot study, students stated that, owing to the AR app, they gained a deeper understanding of lung function and better understanding of physical dimensions. These phenomena are normally difficult to understand when only textual information or an immobile plastic model is employed in instruction. Students also stressed the importance of having the opportunity to choose an individual, explorative approach in order to gain a comprehensive understanding.

### Augmented Reality Sandbox

As a part of a NSF-funded project on informal science education for freshwater lake and watershed science, the Augmented Reality Sandbox was developed as a hands-on exhibit combining a real sandbox, and virtual topography and water (Reed et al., 2014).

What sets this AR apart from most other models is the setup of the system, which consists of a Microsoft Kinect 3D camera, a computer equipped with a simulation software, and a data projector. The setup allows the Kinect 3D camera to measure the distance to the sand in the sandbox, providing data to the computer, which generates a topographic map (Fig. 3). The map is subsequently displayed via the data projector on top of the sand so that the map is fully aligned with the topography of the sand. As the image displayed on the sand is updated in real time, when someone makes changes to the sand topography, the overlaid image is immediately updated. The model also supports water as the display medium. Users can interact with the AR sandbox by digging in the sand to change the topology, or they can keep an open hand over the sandbox, which will be perceived by the software as a rain cloud, resulting in virtual rain emerging from the palm. By using AR in this way, users can experience the relationship between the physical topography of the sand and the virtual topographic maps.



*Fig. 3. Augmented Reality - Sandbox in use*

The AR sandbox is open source. Videos and further information are available at <http://idav.ucdavis.edu/~okreylos/ResDev/SARndbox/>

Following this brief technical introduction to AR, the focus will now shift to the research related to mediating science learning through ICT in general and AR in particular. As emphasized by Laurillard (2004), ICT has the potential to enhance the way science is taught, but only if integrated with inspirational teaching methods.

### **ICT, AR and the learning of science**

In a recent review of AR in education, Radu (2014) noted both benefits (such as increased content understanding and student motivation) and potential challenges (such as usability difficulties and ineffective classroom integration). Among the factors influencing student learning it is in particular highlighted that the content can be represented in multiple ways, i.e. as sound, visualization and animation. Multiple representations can facilitate students' ability to experience phenomena that are otherwise impossible or infeasible, e.g. spatial scales facilitating understanding of the solar system, or speeding time to watch plant growth. Furthermore, by allowing the learner to physically enact the abstract educational concepts through gestures etc., their understanding is greatly increased (Radu, 2014).

#### ***Visualizations and animations***

Many scientific phenomena are impossible to see. For example, magnetic field cannot be observed directly, while other phenomena are unavailable because of the size, such as atoms or galaxies. Time may also be a dimension that limits the observation opportunity for e.g. continental drift. Wu et al. (2013) emphasized that AR systems can support learners in visualizing abstract science concepts or unobservable phenomena, specifically noting the following affordances:

- learning content in 3D perspective
- ubiquitous, collaborative and situated learning
- learners' sense of presence, immediacy, and immersion
- visualizing the invisible
- bridging formal and informal learning.

Munnerley et al. (2012) likewise emphasized the opportunities in relation to mobility, visualization, alternative perspectives and comparison/contrast of multiple perspectives.

#### ***Student inquiry and student-generated representations***

Students' use of multimedia when learning science, e.g. through making unseen processes visible, is also highlighted in the research literature pertaining to ICT in science education in general (Krajcik & Mun, 2014). Simulations and animations are in particular considered to support science learning if encouraging what-if questions (Hennessy et al., 2007, p. 149). An inquiry-based approach is highlighted as central when learning science (Osborne & Hennessy, 2006), and Krajcik and Mun (2014) positively emphasize technology that supports students in the collection, organization, and analysis of data, and the development of scientific explanations connected to this. Looking forward, they call for learning technology to be used by teachers to support students' situated inquiries in real world contexts, referring to the five learning principles of (1) active construction, (2) situated learning, (3) cognitive tools, (4) reference to learning goals and (5) scaffolding to support students in completing challenging tasks (Krajcik & Mun, 2014). Thus, the traditional view of exemplary scientific practice being students' hands-on experiments in the science lab is contemporarily being broadened to include simulation and animation as mediating tools (Hennessy et al., 2007; Krajcik & Mun, 2014). Most importantly, the value of students being active producers when working with simulations and animations is increasingly being highlighted in the research literature (Hoban, Nielsen, & Shephard, 2013; Prain & Tytler, 2012). Students' conceptual gains and greater engagement have been emphasized in research examining contexts where teachers are guiding students in generating their own representations (Prain & Tytler, 2012). It seems that students' engagement with science content is encouraged if they are asked to explain and communicate their knowledge to others, especially if they have ownership in the process and use their own devices combining digital media forms (Hoban et al., 2013). In sum, although AR can appeal to all senses, the visual augmentation and visualization of abstract and complex science concepts and phenomena is in particular highlighted in extant literature. Furthermore, AR allows users to be immersed in the simulations, easily collaborating with peers when discussing complex 3D phenomena that would be difficult to comprehend through other media

(Radu, 2014). In the pertinent literature, there is a call for gaining greater knowledge about educational use of AR being generated close to the educational context, including guidelines supporting teachers in promoting student learning (Radu, 2014). In response to this need, the ambitious aim is to develop a framework to enable teachers and students to become AR producers, closely connected to the science content they are working with in everyday science lessons (Fig. 1), and to base this framework on inputs from the broad range of experts acting in this rapidly developing field.

### Research Questions

- What kinds of benefits and challenges related to augmented reality enhancing student learning in science are identified by an expert panel?
- How could a framework guiding the design and analysis of augmented reality applications for educational use in science education look like based on these expert reflections?

## METHODOLOGY

### A survey inspired by the Delphi method

A two-stage survey procedure inspired by the Delphi method was used asking a cohort of experts from the four countries to identify and reflect on benefits and challenges related to the use of AR in science education. The Delphi technique is a widely used and accepted method for achieving convergence of opinion concerning real-world knowledge (Hsu & Sandford, 2007). Delphi methodology has been applied in various fields of research, including health and medicine (e.g. McDermott et al., 1995) and science education (Osborne et al., 2003). The Delphi methodology is a qualitative approach facilitating systematic identification and analysis of the judgements of individual participants in a panel of experts. Issues are explored through multiple iterations, with two or more rounds of sequential questionnaires concerning a specific topic. Condensations of opinions derived from one questionnaire are included in the next. Due to this approach benefitting from the anonymous group interaction and multiple consecutive iterations, the method is distinguished from other group interrogative methods. The survey participants are ideally experts from a range of related fields (Osborne et al., 2003). In the present study informed judgements from experts representing the three groups of stakeholders concerning AR for learning science, teachers/educators, researchers and ICT-designers (Wu et al., 2013), were correlated.

### Sampling

A purposive sampling strategy was used (Cohen, Manion & Morrison, 2009) identifying nine experts from each of the four countries, comprising of three science teachers, three science education researchers, and three ICT designers.

- An expert science teacher was defined as a teacher with more than 6 years of experience, presently teaching science at secondary level, and haven shown a particular interest in ICT and science education by participating in continuing professional development.
- An expert researcher was defined as presently active in research in the field of science education not necessarily with ICT as a main research focus, but with projects/publications concerning in some way student learning in science and ICT.
- An expert ICT designer was defined as presently active working with technological design and innovations for education, not necessarily for science education in particular.

Project partners from each country made a prioritized list with experts from the three groups and invited participants via email. The recruitment process terminated once three experts from each group consented to partake in the study. It should be noted that, in Norway, only two ICT designers could be identified so, all in all the study involved 35 experts.

### ***The first questionnaire***

The first questionnaire commenced by shortly presenting what augmented reality is, illustrated with an example with a car from Metaio, and exemplifying what AR in education might be with the human respiration application (box 1), however emphasizing that this is first-generation. The questions mainly required open-ended answers with ideas for, and reflections about, challenges/pitfalls related to the use of AR in science education. For example:

- List a range of ideas for the use of AR in science education.
- List what you see as (general) challenges/pitfalls related to using AR in education.
- Now we would like you to present your best 3 ideas for the use of AR.

While the main language of the questionnaire was English, the respondents were given the opportunity to write the open reflections in language of their choice, so some quotes used below are English translations of the originals. From the original participant pool, 80% response rate was achieved with uncompleted questionnaires relatively evenly distributed among countries and expert groups: the final 28 respondents consisted of 10 teachers, 9 researchers and 9 designers; 9 experts from Denmark, 7 from the UK, 6 from Spain and 6 from Norway.

### ***Data- analysis***

The reflections were analysed in an iterative process of databased categorization and coding (Cohen et al., 2009). In the first step the answers to the individual questions were categorized. Based on the reflections across the range of questions, in the next analytical step a range of dimensions were identified. After the final coding the various dimensions could be condensed in eleven continua: the preliminary framework (table 1). We, like Munnerly et al., 2012 use the term continuum to describe a sliding scale with an innovative dimension at one end. For example, user interaction with elements on the screen is an innovative dimension, identified based on the data, and at the other end of this continuum is the user only observing something happening at the screen, mentioned as a pitfall in some reflections.

### ***The second questionnaire***

The second questionnaire mainly comprised of closed questions, whereby the participants were asked to rate the importance of the various innovative dimensions condensed from the first questionnaire. The aim was to achieve a kind of consensus. The participants were asked to rate the dimensions on a 7-point scale, anchored at 0 = not important, to 6 = very important. They were additionally given the opportunity to comment on the dimensions. Furthermore, the participants were asked to rate (on the scale from 0 to 6) the particular human respiration application according to these dimensions. This questionnaire was answered by 51% of the original experts (18 respondents). All expert groups were well represented, with 5 expert science teachers, 6 ICT designers and 7 science education researchers - four experts came from Norway, Denmark and Spain, while six originated from the UK.

### **Refining and testing the framework**

The preliminary framework was refined based on the findings yielded by the second questionnaire, e.g. the preliminary eleven continua were condensed to nine. The framework was tested in a process of three researchers separately rating the same AR applications. When comparing ratings using the final framework with nine continua, ratings were established both on a seven-point scale (0-6) and a five-point (0-4) scale. The descriptions of the dimensions were refined and specified as a part of this iterative testing process. The seven-point scale was chosen, as it was deemed more suited for obtaining a greater level of detail. In addition, it yielded a high inter-rater reliability.

## FINDINGS AND DISCUSSIONS

Findings from the two stages of the survey are presented separately. First we present some categorized reflections in relation to the individual questions, resulting from the first step of the qualitative analyses. These consecutive findings referring to RQ1 are gradually condensed and discussed, leading into the answer to RQ2.

### Benefits and pitfalls of AR identified by the experts

The participants identified both benefits and challenges in relation to using AR in science education, and contributed several concrete ideas. In relation to benefits, almost 50% of the respondents mentioned examining internal structure and processes, which are otherwise invisible or hard to understand for students. Though there might be some kind of priming effect of the lung see-through app (box 1), used in the questionnaire to exemplify first-generation AR, we see this as the core of educational AR, describing the overall affordances in relation to student learning. Many of these reflections specifically refer to the possibility of 3D visualization:

Dynamic images of a process. 3D images. Vision of places where is not possible to be (atoms, livings, space).

The potential for situated learning was mentioned directly or indirectly in 15% of the reflections, such as:

AR can add content to surrounding environment.

Likewise, 15% of the respondents mentioned possibilities for interactivity and a creator perspective. One expert noted:

Allowing students to explore rich astronomical measurement databases, as if they themselves were directing and focusing the telescope and conducting the measurements.

Many of these reflections also refer to student inquiries and a data-driven perspective, as exemplified by the quote referring to using so-called astronomical big data. Creating opportunities for student collaboration and references to socio scientific issues, such as climate change and renewable energy, was also noted (see additional quotes in Table 1).

In relation to pitfalls, technical barriers and lack of resources in class was the most frequently noted category (25%). Both teachers and educational researchers referred to this pitfall, with one teacher stating:

The availability of tablets and other hardware within e.g. the classroom setting.

Another frequently cited category (20%) was condensed as truly educational use. It is exemplified by the two quotes from educational researchers:

The major pitfall I see is poor tools that end up doing more harm than good. AR tools (as it goes for any technology) are not an added value in itself; they need to be well suited for the purpose, i.e. developed with a clear focus on requirements/constraints derived from an educational perspective (learning effect).

Ensuring that AR is adding value and is not seen as a gimmick [...] develop an app which is truly educational and address a requirement in science.

The frequent lack of opportunities for interaction when students are working with the currently known AR applications was mentioned by 15% respondents from all expert groups. As one designer noted:

Users are often more spectators than interactive participants. The screen is always in the centre.

Similarly, a researcher stated:

To support learner interactivity. I think that learners need to experiment and interact in order to have a sustainable tool.

Finally, a teacher, focusing on the pitfalls that could arise if technology replaces interactive real time inquiries, stated:

If you stop doing the real investigations and inquiries.

There were no significant differences across countries or the three groups of respondents. However, a minor tendency toward focusing on concrete technical and practical barriers in the classroom was noted among the teachers. Similarly, some designers referred to technical challenges and the dilemma pertaining to the need for investing money and time into design of educational value in a field characterized by constant and rapid development.

Summing up, given the character of the methodology with respondents answering individually, the consensus in relation to all three groups of experts having a clear focus on potential learning opportunities is noteworthy.

### Concrete science examples

The concrete ideas suggested by the respondents covered a wide area of science topics. The following comment exemplifies how interactivity and student inquiries might be incorporated into an AR app:

Human anatomy: e.g. look inside a body to investigate organs and how they function individually and together. Potential interactions: what happens if the liver is reduced to half the size? What happens if the amount of red blood cells is increased by 10%? Travel inside the human body: as a blood cell passes through veins/arteries/the heart, a sperm cell travelling through an ovary.

The possibilities for student working with the so-called socio-scientific issues is referred to in the following quotes with reference to situated learning and an element of gamification, respectively:

Show dramatic consequences of climate change on known central locations/places.

Build constructions for renewable energy. Story: energy crisis, where the mission is to solve it by finding renewable energy sources.

However, many other examples illustrate how what can be seen as classical (value-free) science content can be presented taking advantage of the AR capabilities with respect to juxtaposing perspectives, as shown in this excerpt:

Layering information Learning Objective: Understanding photosynthesis. Incorporate layers of information about a leaf, such as the cross-section through a leaf cell and the many different components, e.g. lower/upper epidermis, stoma, wax cuticle, spongy mesophyll, to explain the function of these components. Equations associated with photosynthesis: carbon dioxide + water (+ light energy) = glucose + oxygen.

As in the general reflections, it is also evident in the concrete examples that the respondents are focusing on learning opportunities/objectives, and referring to science content known from research to be hard for students to grasp.

### Developing the framework

It became apparent from the databased analyses that a certain innovative educational dimension could best be described on a sliding scale: as a continuum. The representation as continua is partly inspired by Munnerly et al. (2012) describing a continuum from virtual reality to augmented reality. The naming of the dimensions emerging from the iterative databased analyses was also inspired by extant research (table 1).

Table 1: Preliminary framework with eleven continua

Continua	Description	Examples/quotes
From the user being an observer to designs with interactive elements	The continuum targets the degree to which the user interacts with the AR materials. Interactivity is the dimension mentioned most frequently in the open reflections, and this is also widely referred to in the pertinent literature.	<ul style="list-style-type: none"> <li>• The limitation of this AR example [ed. note: Human respiration] is that (apparently) all the user can do is to watch.</li> <li>• One could implement tasks where you could interact with elements on the screen.</li> </ul>
From the user being a consumer to designs where the user is also creator	The continuum targets the degree to which the AR offers the user the possibility to actively create something. The innovative dimension was first named producer, but was later renamed to creator, as teacher/students producing AR is used to describe activities in the next stages. Being a creator involves more than interacting with elements on the screen. It can, for example, be that the user is drawing or building something, e.g. using molecular building kits (quote), or including virtual version of building sets.	<ul style="list-style-type: none"> <li>• One owns [...] speculations about the thing</li> <li>• An app which can 'read' molecular building kits and tell the students which molecules they have built</li> </ul>
From the user working individually to designs where collaborative work is incorporated	The continuum targets the degree to which a requirement for users' collaborative work is built into the AR design.	<ul style="list-style-type: none"> <li>• A game about immune-defence [...] students are organised in groups, some have to defend the body</li> <li>• in a group/class like this one could even use the Wi-Fi to connect several students to cooperate on these tasks</li> </ul>
From designs decontextualized from a certain context to designs facilitating situated learning	The continuum targets the degree to which the AR is designed to be used in a specific setting, situation and/or location.	<ul style="list-style-type: none"> <li>• How will the 'thing' under investigation behave at a specified location</li> <li>• [...] to study ecosystems</li> <li>• [...] related to soil maps [...] student knows that he/she is in an area which is elevated seabed and was covered with 1 km of ice 12,000 years ago</li> </ul>
From designs supporting content-oriented learning of science to designs supporting inquiry-based science education	The continuum targets the degree to which elements highlighted in inquiry-based science education are built into the AR; e.g. if students are required to actively create meaning by posing questions and hypotheses, collecting and analysing data, and communicating their findings.	<p>[About student questions]:</p> <ul style="list-style-type: none"> <li>• Look into the body [...] what happens if the liver is reduced to half the size? What happens if the amount of red blood cells is increased by 10%?</li> <li>• Addressing one's own questions/speculation about 'the thing' instead of addressing issues defined by the teacher or the textbook</li> </ul> <p>[About hypotheses]:</p> <ul style="list-style-type: none"> <li>• To imagine [...] how the physical phenomenon or process was developed</li> </ul>
From static designs to designs being data driven	The continuum targets the degree to which data can be collected and represented while using the AR-browser. This can be real time data collected with the device using sensors built into the device (e.g. motion and GPS), or add-on sensors (e.g. temperature, heart rate), or it can be data from open databases.	<ul style="list-style-type: none"> <li>• Exploit open data from national databases for local visualisation and display</li> <li>• Heart rate monitors that can be connected to the 'lung-app', so you will be able to show the heart beat in real time and actually see the difference</li> </ul>

<p>From having a mono-perspective to juxtaposing different perspectives</p>	<p>The continuum targets the degree to which the design allows a particular location/issue to be seen from more than one perspective, whereby the user can choose to remove or add certain layers of augmented content about the same phenomenon. This can, for example, include zooming in and out and seeing both micro and macro perspectives, using spatial scales to see the solar system from various perspectives, or seeing a site in different historical periods.</p>	<ul style="list-style-type: none"> <li>• Elements of the human body—layered AR illustrating skin, nerves, organs, bones etc.</li> <li>• A specific geographic location, say, in a city or a particular landscape: how did the place look 10, 100, 1000 years ago, how/why did it change?</li> </ul>
<p>From classic multi-media to 3D visualisation</p>	<p>The continuum targets the degree to which 3D visualizations are present in the design. Examples of classic multi-media might be a design relying on still images/illustrations or playing video or soundtracks.</p>	<ul style="list-style-type: none"> <li>• 3D-visualisation of 3D landscape with cities [...] solar system, eclipses that are difficult to explain</li> <li>• 3D mask with e.g. oculus rift a head-mounted 3D display]</li> </ul>
<p>From a virtual reality setting to real-world augmentation</p>	<p>The continuum assesses to what degree real world inquiry is built into and plays an important part of the AR design. A virtual design might be addressing real-world issues, but the real world might not appear as an element of the design once the app is launched. The continuum refers to virtual reality (VR) and AR in a sliding scale of mixed reality (Munneerly et al., 2012). The virtual end of the scale is also describing the situation where a model representing a real world situation or phenomenon is the focus of an inquiry.</p>	<p>[Real world augmentation]:</p> <ul style="list-style-type: none"> <li>• Periodic table in real applications, such as going treasure hunting for chemical elements in your neighbourhood</li> <li>• Show dramatic consequences of climate change on known central locations/places"</li> </ul> <p>[Virtual reality, for example virtual labs]:</p> <ul style="list-style-type: none"> <li>• Students perform a virtual experiment</li> </ul>
<p>From no game-like elements to gamification</p>	<p>The dimension gamification targets to what degree game-like dimensions—such as competition, scoring and rewards—are built into the design.</p>	<ul style="list-style-type: none"> <li>• A game about immune-defence where students carry a 3D mask (e.g. oculus rift). They work in groups where some have to defend the body and others attack as bacteria and viruses</li> <li>• A game where learners are grouped and are asked to travel through the galaxy to do some kind of treasure hunt</li> </ul>
<p>From content being classical value-free science to content concerning socio-scientific issues with a dimension of decision making</p>	<p>The continuum assesses to what degree the science content is related to issues where decision-making, values and ethics are important elements.</p>	<ul style="list-style-type: none"> <li>• Engaging students with a role-playing universe, where they can encounter real-life decision-making related to socio-scientific issues</li> <li>• Input about cloning and [...] decision making [...] other dilemmas could be about climate, nuclear power</li> <li>• Renewable energy, where a new solar cell has to be built to save an area from an energy crisis</li> </ul>

In the process of iteratively working towards a framework we tried illustrating the continua in various ways, e.g. as a radar diagram (Fig. 6 below). Furthermore, in the team of researchers, we assessed the robustness of the framework by coding various currently available apps. In this process, we additionally experienced the benefits of the framework in meditating discussions of what was important in a certain app in relation to particular intended learning outcomes. We also identified some challenges, in particular in relation to coding in a reliable way with the preliminary eleven continua. The aim of the second questionnaire was thus—in addition to the original aim of achieving consensus—to test reliability of the preliminary framework by asking the experts to rate a certain AR app.

**Findings from the second questionnaire**

The experts were asked to rate the importance of the 11 dimensions. By ‘dimension’ we mean the innovative end of each continuum. The average ratings are represented in Fig. 4.

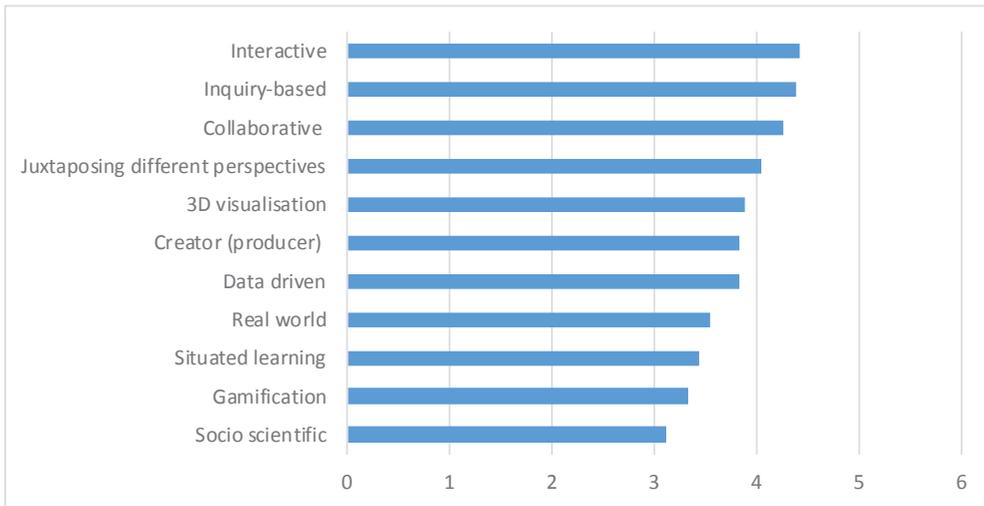


Fig. 4. Average rating of ‘How important do you find the xx dimension’, from 0 = Not important to 6 = Very important (n = 18).

Based on the average scores, the most important dimensions seemed to be the ‘interactive’, ‘inquiry-based’ and ‘collaborative’. The least important dimensions, according to the experts, were the ‘socio-scientific issues’ and ‘gamification’. It must be noticed, that these two dimensions, are rated on the second half of the scale (Fig. 4). However, revisiting the original reflections from the first questionnaire in a second analytical iteration, it was notified that the reflections about gamification and the socio scientific dimension often were part of statements from the experts also involving other dimensions as in the quote referred to above:

[..] climate change on known central locations/places [..]

Here a main focus is students’ situated experience and the socio scientific issue climate change is an element in this. The same can be said in relation to gamification e.g. as an element working with renewable energy at a certain location:

[..] the mission is to solve it by finding renewable energy sources.

Not surprisingly, the expert designers were a little more positive than were teachers and researchers about gamification (see more about expert groups below). Some experts however referred to gamifi-

cation as an element that might be targeted under the headline of the other dimensions and furthermore a perspective of AR being engaging and motivating in itself was mentioned - to top it off with gamification might be overdoing things:

I think this is not key [...] AR alone already seems engaging enough to students

The good side is that students are more engaged when it is presented as a game, but it is also interesting to face the learning as a real task.

Our conclusion is thus that the possibility to refer to specific socio-scientific issues, and to incorporate game-like elements, such as competition, scoring and rewards in educational AR designs certainly needs to be considered, but the decision was not to represent these two dimensions separately in the final framework.

### **Ratings and reflections from the three expert groups**

Before illustrating how the final framework with nine continua can be used in an analysis of augmented reality applications some additional results from the second questionnaire are presented, related to the differences in ratings when divided on expert groups and countries.

The inquiry-based dimension was rated the most important by the science teachers, with an average score of 4.7 (Fig. 5). Gamification was, on the other hand, rated less important, with an average of only 2.7. Conversely, the ICT designers rated the gamification dimension a little higher, with an average score of 4.4, however still with rating the interactive dimension higher (Fig. 5). The researchers rated the data-driven dimension higher than the other expert groups, but they also rated the interactive dimension higher (Fig. 5).

With respect to the countries, the Danish experts in general seemed to be a little less positive with respect to rating the general importance of the dimensions, especially the socio-scientific dimension (with an average score of only 1.7).

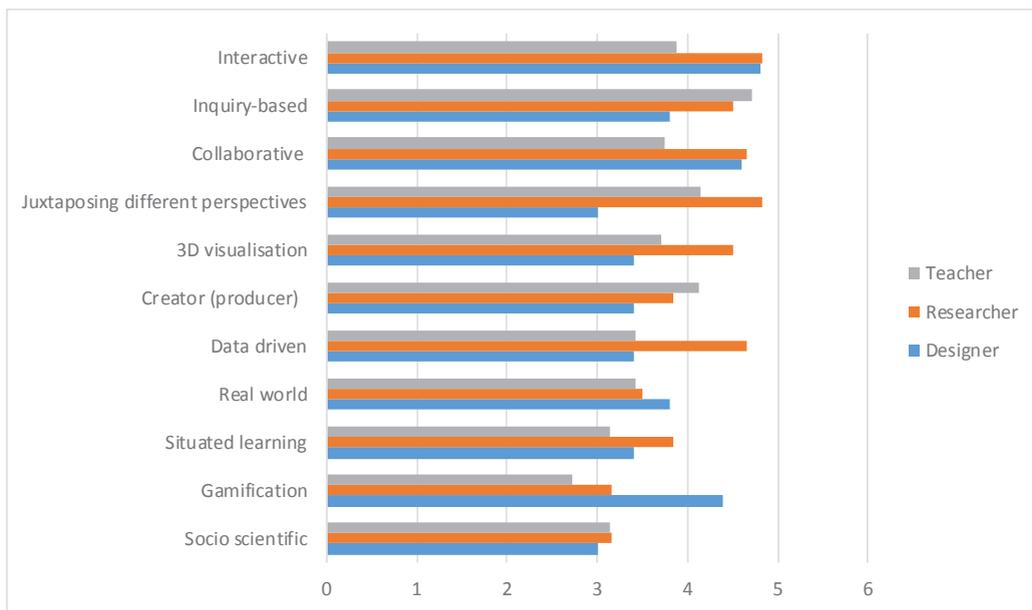


Fig. 5. Average rating of 'How important do you find the xx dimension' based on the responses of the three expert groups.

So – though the expert teachers were a little less enthusiastic than the ICT designers and educational researchers the interactive dimension was in general deemed the most important, with an average rating of 4.4. The comments from participants on this dimension include:

Interactivity, because students will be more involved and will implement critical thinking, decision-making, etc.

Inspection without interaction does (in general) little to enhance learning.

It is important to note, that this dimension can be differed from the creator dimension, while being a creator involves more than interacting with elements on the screen. It can, for example, be that the user is drawing or building something, e.g. using molecular building kits, or including virtual version of building sets (Table 1). The creator dimension was rated with an average score of 3.8 (Fig. 5). Summing up on this, it could be inferred that some kind of interactivity needs to be addressed in all AR designs, and that this in some designs, aligned to certain learning outcomes, can be extended to also involve a creator perspective.

**Using the framework to analyse augmented reality applications**

As a final part of the second questionnaire, the participants were asked to rate the human respiration app according to a short description of the framework. These ratings were used in the assessment of inter-rater reliability. The process revealed that some dimensions, such as data-driven elements, were well conceptualised, while others required a clearer description to ensure reliable coding. Consequently, the description of the final nine dimensions was developed.

The final coding of the two examples of the first-generation apps described above is represented in Fig. 6. The sandbox is rated relatively highly with respect to interactivity and a creator perspective, while the human respiration app received relatively high scores in relation to real world augmentation.

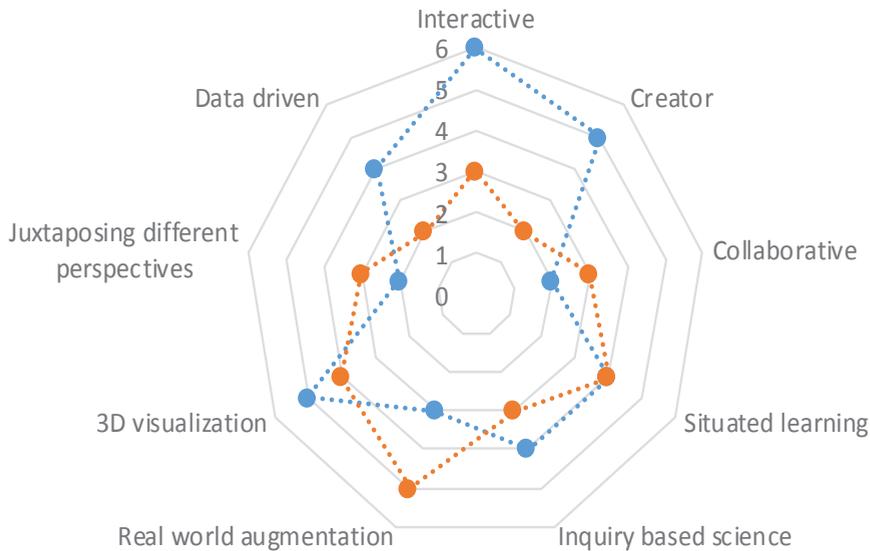


Fig. 6. The two examples of first generation educational AR are coded using the nine continua from the final framework. Blue: Sandbox. Red: Human respiration.

## DISCUSSION AND PERSPECTIVES

A central finding is that all three expert groups referred to the development of AR technology for education as only being important if explicitly considering how the technology is mediating student learning of relevant science content. Even the expert multimedia designers were concerned about AR designs being meaningful pedagogically, as exemplified in quotes referring to truly educational value. Thus, the principle of starting from the learning objectives and approaching the technology with a clear sense of what it aims to achieve for learners (Laurillard, 2004) seems to be widely acknowledged.

In relation to the kinds of opportunities and challenges identified related to augmented reality enhancing student learning in science, interactivity was the issue raised most frequently by the experts. It is highlighted as a challenge if students are only watching an animation - they must be given opportunities to change what is happening in the AR visualizations. For example, in the first-generation Sandbox app, the overlaid image was immediately updated when students made changes to the sand topography. Human respiration, the other first-generation app was not rated as highly on the interactivity dimension as was the sandbox. A clear limitation is that students are viewing a fixed video illustration in 3D of how lungs are working in a human body, and can only interact by zooming in and out. These findings supplement the affordances identified by e.g. Wu et al. (2013). So, learning content in 3D perspective as in the human respiration app is one of the evident AR-affordances, but possibilities for interaction between students and screen might further qualify this in a learning perspective. An interesting detail is that the teachers' rating of the importance of interactivity was slightly lower than that given by the two other expert groups. This might indicate that, owing to their daily work among students, teachers recognize that designing interactive tasks can be challenging.

The second most important dimension is building elements highlighted in inquiry-based science education into the AR applications. For example, students could be required to actively create meaning by asking their own what-happens-if questions (Hennessy et al., 2007), and by posing or choosing among hypotheses before collecting and analysing data. In that way, the technology is not only enhancing but also transforming student inquiries in science - a differentiation often made when discussing ICT in education. In addition, the AR application might also support the students' exploratory talk about science phenomena known to be vitally important when learning science (Krajcik & Mun, 2014). Another important part of student inquiries in science is to support them in communicating about their findings. Thus, direct suggestions for promoting this aspect could be a part of the AR-designs. Opportunities for student inquiries and a creator perspective as important dimensions to target is well illustrated by a quote from one of the experts:

We are not offering learners the opportunity to imagine and visualize things.

This supplements the affordances of learners' sense of presence, immediacy, and immersion when working with AR emphasized by Wu et al. (2013).

The experts have also contributed by providing specific ideas for relevant science content areas. Radu (2014), for example, emphasized the need for research aiming to identify types of content that can be effectively taught using AR, and specifically contexts where AR technology might be more effective than other educational modes. Based on the rich qualitative data, it is clear that AR might support student learning of traditional science content. In particular, students studying processes in ecosystems, i.e. photosynthesis, for example, would benefit from incorporating layers of information and a cross-section through a leaf, as suggested by one of the experts. This supports the affordances of visualization and multiple perspectives e.g. emphasised by Munnerly et al. (2012). Other suggestions from the experts are targeting science content in relation to areas, such as renewable energy and climate change. Socio-scientific issues were not included in a specific continuum in the final framework. Nonetheless, considerations regarding student discussions and decision-making related to issues such as renewable energy and climate change must be seen as important based on the findings. It is in some way a limitation of the present study that the experts' ratings of the preliminary dimensions turned

out to be rather close, so the decision to present a final framework with only nine continua was partly made based on pragmatic considerations related to inter-rater reliability.

This leads on to the second research question. Radu (2014) emphasized the need for guidelines for designing effective educational AR experiences, i.e. tools supporting teachers in promoting student learning. Based on our experiences so far, we suggest that the framework presented can be used both in the process of designing new AR applications, and in analysing various applications already developed. When using the framework in designing and analysing AR technology, it is however important to emphasize that not all AR designs are expected to score high in relation to all nine innovative dimensions. Reference to learning goals is important when designing educational AR (Krajcik & Mun, 2014), and the ideal balance between the various innovative dimensions represented in the framework depends on specific learning goals. The visualization in a radar diagram as illustrated above can support decisions pertaining to intended learning outcomes connected to the educational use of a certain application. In the present process of designing and piloting second-generation apps in the project we have come to appreciate how the framework can mediate discussions of what is important in a certain app in reference to specific intended learning outcomes. For example, an app named 'lost in the woods' has been developed, targeting learning goals across the four countries of lower secondary students understanding the nature of models and their use in science. Students are, as part of their situated inquiries, expected to place AR-markers (Pence, 2010) launching a range of animations of processes related to photosynthesis at various position on a tree: roots, trunk, leaves etc. and to assemble this into their own multimedia presentations explaining both the processes, and the possibilities and challenges using different models ([https://ar-sci.cesga.es/index.php/Lost\\_in\\_the\\_woods](https://ar-sci.cesga.es/index.php/Lost_in_the_woods)). This app is designed to target the dimensions of creator, collaborative, inquiry based science and situated learning to a rather high degree, while a data-driven perspective, e.g. potential use of big-time data, has not been specifically considered.

Summing up, the expert panel contributed with a range of benefits and challenges related to AR enhancing student learning in science. There was consensus among experts in relation to a focus on 'learning before technology' and they in particular supplemented affordances identified based on literature with new perspectives related to interactivity and a creator perspective and with detailed examples of how the technology can be used in student inquiries in science. Expert reflections were condensed into innovative dimensions all placed in a final framework with nine continua - exemplified for use in both analysis of existing first-generation apps and in design of new second-generation apps.

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