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SEEING THE UNSEEN—SPATIAL VISUALIZATION OF THE SOLAR SYSTEM WITH PHYSICAL PROTOTYPES AND AUGMENTED REALITY

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The presented design case gives examples of designing an Augmented Reality learning scenario about the Solar System with 6th grade. The case connects the physical and virtual worlds in Augmented Reality, like 3D planetary globes floating above the textbook. This way, students can interact with digital information embedded in the physical environment.

The stakeholders in the design process consisted of researchers in the role of designers, while teacher and students were co-designers and informants. During the process, several physical and digital prototypes were developed and tested.

Through the co-design development process, it became clear that the design affordances of Augmented Reality together with the scholastic content of the Solar System invited design potentials such as visualising far away objects by bringing them near i.e. being able to see what is otherwise difficult to perceive. Through the development process, the design potentials of Augmented Reality acted as a lens to access distant realities; included herein visualisation of planet sizes, their relationships, and movement pattern

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INTRODUCTION

This design case contributes, in a Danish context, to the examination of designing an Augmented Reality application with a teacher and students in a 6th grade classroom. The case includes presentations on design decisions in relation to the design affordances (Gibson, 1986; Norman, 2002) of the technology in its current form. Affordance is understood as action possibilities perceived by users. When used in connection with the design of augmented reality, affordance points to design possibilities available in and with the technology. To the best of our knowledge, this innovative case represents an unprecedented experiment in Danish education, although collaborating schoolteachers and researchers are conducting other experiments in Danish schools.

The design process consisted of physical and digital prototypes for spatial visualization of the Solar System. The digital prototypes were based on Google Cardboard and smartphones (Google Cardboard, 2016; see Figure 1).

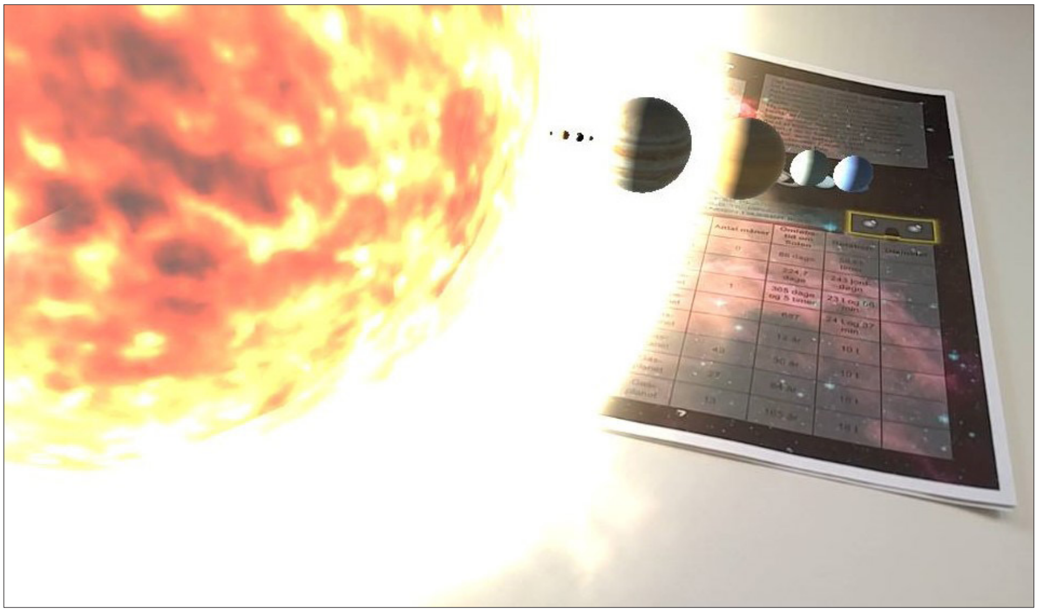


FIGURE 1. The Solar System hovering over a textbook seen through Google Cardboard.

FIGURE 2. Google Cardboard

Google Cardboard was chosen since it is affordable on tight school budgets (see Figure 2), thus making future dissemination of the developed app more likely. The cardboard format is also flexible because it can handle a wide variety of different smartphones. We decided to use smartphones to situate the design and its process in the school environment (Klopfer, 2008). It was also a consideration that the final outcome could expand or to some degree change the traditional approach to schooling (Gee, 2004). The design centered on the affordance of image-based augmented reality (Dunleavy, 2014; Klopfer & Squire, 2008) to mix physical and virtual content. The Augmented Reality application uses a smartphone camera to trigger 3D-content in real time. In the final version of the application, students would be able to see the sun and the planets hover over the book's pages.

The design intention was to work towards and create an immersive virtual 3D experience (Calleja, 2007; Murray, 1997; Salen & Zimmerman,

2004) and to get a clearer picture of the Solar System and its organization. The Augmented Reality design mixture of the physical and virtual worlds intended to promote an engaging learning experience, making otherwise unobservable objects visible in a learning context. The plan was to design an application that could motivate students to explore subjects they were otherwise unable to experience first-hand in the real world (Kerawalla, Luckin, Seljeflot, & Woolard, 2006). Kolb (1984) pointed to concrete first-hand experiences as key ingredients in learning processes, causing the student to reflect and understand abstract concepts in a fertile learning environment. This should also be understood as an aspect of the design process.

In the current project, the 6th grade students and their teacher were active participants in a design-based learning process covering several project phases. This aspect of the project was inspired by Druin (1999; 2002). In it, design, process, and learning go hand in hand to generate and promote design knowledge and learning insights. Thus, they place students in roles as both informants, learners, users, and designers.

The learning perspective is based on experimental and constructionist learning processes where students learn while experimenting and constructing, supported by technology, as described by Papert (1980) (Bertel & Rasmussen, 2013; Blikstein, 2013; Caprani, 2015; Ejsing-Duun & Misfeldt, 2015; Larsen & Majgaard, 2016; Majgaard & Lyk, 2014; Majgaard 2015; Majgaard, Hansen, Bertel & Pagh, 2014; Nielsen, Pedersen, & Majgaard, 2015; Resnick, 2009).

In the current project, the students worked with the Solar System, which is a theme in the curriculum (Subjects and Curriculum, 2017) in Danish primary and secondary schools. The students and their teacher co-designed (Druin, 2002) and developed ideas, fleshed them out, and tested three-dimensional physical prototypes for the digital material. This design process formed the basis for the digital visualization of the Solar System in Augmented Reality. Technical experts programmed the application.

The article is structured as follows: first, the concept of Augmented Reality and Google Cardboard is introduced, along with Virtual Reality as a special form of augmenting. The design decisions, explaining why we chose to work with those technologies, are outlined. Then we describe the design process, with examples that illustrate and inform design decisions. Subsequently we discuss the design affordances based on the technological possibilities springing from working the physical and virtual world, and how these can stimulate the design and learning. Furthermore, we discuss the design potential, challenges, and prospects for the use of Augmented Reality in learning contexts.

SITUATING THE DESIGN CASE

The reason why we chose the Solar System as the case for our design process sprang from a teacher's desire to bring the distant planets up close in a 3D-setting. Students often find it difficult to understand spatial concepts and phenomena when presented either through geometric formulae or text and 2D illustrations (Shelton & Hedley, 2002). Shelton & Hedley (2002) describe this challenge as the spatial learning problem. Martín-Gutiérrez et al. (2009) and Cheng & Tsai (2012) suggest Augmented Reality as a possible platform for addressing the spatial learning problem. Cheng and Tsai examined 12 Augmented Reality projects and found that image-based Augmented Reality could support the students' spatial understanding, practical skills, and conceptual understanding. This of course presented us with the challenge of how to design a learning application that took account of the spatial learning problem.

Augmented Reality is an emerging technology utilizing mobile and stationary devices such as smartphones and tablets (Dunleavey, 2014). Augmented Reality blends the physical and virtual environment (Klopfer 2008; Klopfer & Squire, 2008; Milgram, 1994; Kerawalla, Luckin, Seljeflot, & Woolard 2006; Cheng & Tsai, 2013; Dunleavy, 2014). This mixture can be illustrated as a continuum between physical reality and the virtual environment (see Figure 3; Klopfer, 2008; Milgram, 1994). In physical reality, we interact with familiar surroundings, while the augmented version expands the physical reality by adding a digital overlay.

Augmented Reality is often divided into two types. The first is position-based; the other image-based. These may of course be combined. The position-based Augmented Reality is based on your physical location. Text, graphics, sound, video and 3D models are presented, depending on GPS coordinates or compass measurements, for example (Dunleavy, 2014). The image-based type of Augmented Reality uses the camera on a smartphone or tablet to scan a QR code or 2D image, enabling 3D simulations to show up on top of the image (Dunleavy, 2014; Cheng & Tsai, 2012). We used the image-based type in this project.

Augmented Reality is closely related to Virtual Reality and is characterized by completely enclosing the virtual environments in which the user receives visual and audio inputs through a special headset (Majgaard & Lyk, 2015).

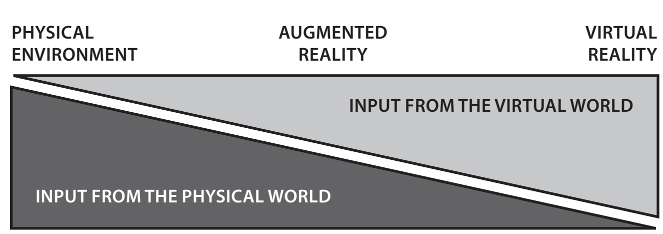


FIGURE 3. Augmented Reality described as existing in a continuum depending on the design.

These virtual environments cut off visual inputs from the physical environment (Mantovani, 2003). The term "immersion" is constantly linked to Virtual Reality and describes a complete, intense and immersive virtual experience (Salen & Zimmerman, 2004; Waterworth & Riva, 2015). Murray (1997) compares the experience with the feeling of being surrounded by water and experiencing the world from a new perspective.

Augmented and Virtual Reality are becoming more common. One no longer has to buy expensive equipment but can use ordinary smartphones and tablets as digital media. This makes it possible for state schools to adopt the technology in their learning environments. Additionally, simple as well as advanced applications can be developed in the 3D-game development tool Unity. In Denmark, this Danish tool is often used as a basic game development tool in higher education (Majgaard & Lyk, 2015). These two constitute practical reasons why we chose Augmented Reality along with Google Cardboard as the technological background for our design case of designing a learning application about the Solar System for 6th graders.

Examples of Augmented Reality as educational tools

In an educational context, Augmented Reality can be used to visualize objects spatially and temporally. That is bringing the very small or far distant within perceivable range. This can be done by upscaling the microscopic, downscaling the macroscopic, or by making the interior exterior—all to make the unseen seen (Dunleavy, 2014). An example of making the interior exterior is an image-based Augmented Reality application for teaching anatomy to student nurses (Buhl & Rahn, 2015). In this example, the students pointed the tablet camera at each other's chests and saw three-dimensional virtual lungs pulsate in front of their chests. In practice, a particular logo printed on paper was attached to the chest and the app "read" the logo and executed the virtual 3D lung simulation. Such augmentation is a kind of wearable enabler worn on the body. These design possibilities and affordances present interesting challenges: how exactly to design augmented reality to achieve our desired learning goals of visualizing and scaling the Solar System in a comprehensible way?

Our design study draws on previous casework using Virtual Reality related to visual arts education in 5th grade. In that study, the students participated in a design process in groups in which they designed and built physical 3D installations using art materials. The idea was to design places they wanted to visit, such as the pyramids in Egypt. Subsequently, the installations were scanned digitally and the students could visit the sites in Virtual Reality using the Oculus Rift headset. It gave students a mediated (Bolter & Grusin, 2000) experience of visiting faraway places by discovering, at first hand, how their physical design was up-scaled and digitized into a 3D world. (Majgaard & Lyk, 2015).

In the fall semester of 2016, we had a group of our master's students prototype Augmented Reality visualizations of

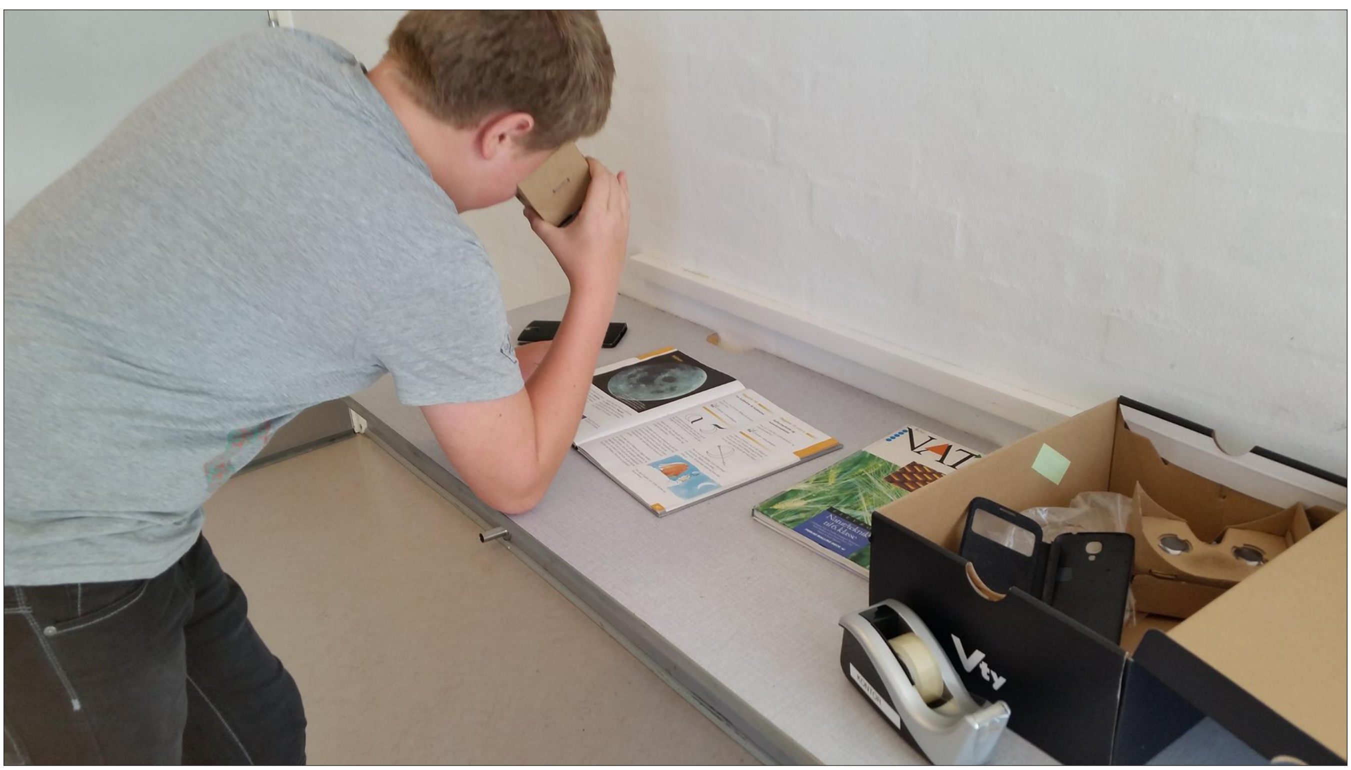


FIGURE 4. Student looking in the science book with Google Cardboard and seeing an augmented Moon

chemical reactions under the theme series reactivity of copper, lead, and aluminum in salt water. The idea was to design an application with which 8th graders could learn how orbiting electrons jumped from one element to another during chemical reactivity processes (Statoua, Bunkenborg, Petersen, Therkildsen, & Ajjawi, 2016).

Description of the project's technological platform

Google Cardboard is a pair of cardboard glasses with a set of plastic lenses which, together with a smartphone, transform into a simple virtual-reality headset. It is done by placing the smartphone in a pocket in a Cardboard headset (Google Cardboard, 2016; Google Cardboard v1.2, printing template, n.d.; see Figure 4).

On Google Play (or similar) you can download existing games and simulations for both Augmented and Virtual Reality (Google Play, 2016). Unity developed image-based Augmented Reality applications for Google Cardboard, which requires a third-party add-on called Vuforia (Vuforia Developer Portal, 2017).

FRAMING THE DESIGN CASE

We used flexible and participatory design processes inspired by Extreme Programming and Cooperative Inquiry. Extreme Programming focuses on participatory design where the product is continuously adapted to interact with user feedback (Serena, 2007; DeGrace & Stahl, 1991). Cooperative Inquiry is developed by Druin (1999; 2002). Druin's approach to design with children has three specific aspects (Druin, 2002):

- Multi-disciplinary partnership is a design case consisted of students, teachers, and researchers. The target group was 12 students from a 6th grade and their science teacher.
- Field Research in the students' environment, e.g., the classroom contributes to a better understanding of the target group's context, activities, and artefacts.
- Iterative development of low- and high-fidelity prototypes comprises multiple rounds of design, testing, and evaluation. In this design case, three iterations took place over six months, when the class explored, tested and came up with ideas for the continued design process.
- The participatory design process was chosen since it empowers stakeholders by giving them influence and ownership over both the direction of the development process and of the content of the developed material. By doing that participation and developmental motivation is enhanced, which was clear in both the teach and children's case.
- On a practical day to day level, both the teacher and children in the design process facilitated dialogue and experiences that brought about insight to the design analysis and suggestions that would otherwise be overlooked or simply missed.
- Choosing a participatory design approach helped in sorting out difficulties of understanding of the solar system thereby getting ideas for developing our augmented reality application.

The following gives examples of the initial explorative investigation followed by three iterations of the development process along with design decisions.

INITIAL EXPLORATIVE STUDY AND ESTABLISHMENT OF COMMON DESIGN GROUND

The initial design intervention with students took place at their school and aimed at preparing them and their teacher to engage in a multi-disciplinary design team. It was therefore important to build a common repertoire or conceptual framework. The meeting consisted of three activities: review of concepts for Augmented Reality and Virtual Reality, test of the technological platform (Google Cardboard with smartphone), and semi-structured interviews. The purpose was to determine the structure and scholastic content of the design case.

The students tested Augmented and Virtual Reality. Students and teacher were introduced in groups to Google Cardboard. They tested the Virtual Reality application Tuscany Dive, a garden-and-house simulation (Tuscany Dive, 2914) and the Augmented Reality application Table Zombie (TableZombies Augmented Reality, 2016). The app generates walking zombies, which the player must shoot to survive.

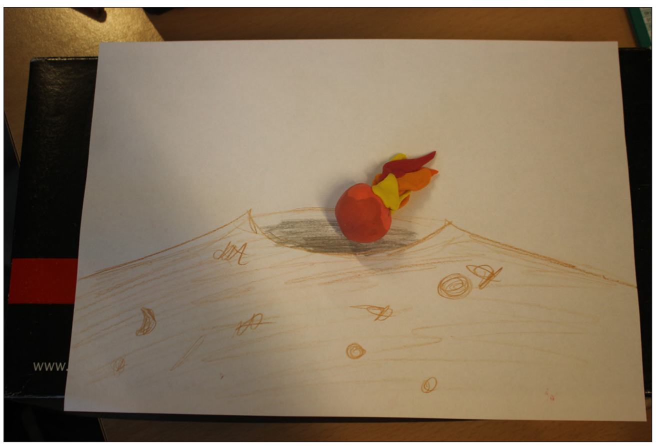
Results: The students did not know the concepts of Augmented Reality and Virtual Reality, but they quickly understood the difference between them. The students were very surprised and excited about the Tuscany Dive application. They quickly understood the simulation and reached for the virtual objects they saw. A student stopped suddenly and exclaimed "... I was just about to fall down [from a balcony over the water]." None of the students had previous experience with anything similar. They therefore found it very impressive. The semi-structured interview with the teacher discussed applications of Augmented Reality and Virtual Reality in education. The teacher saw the potential of using Augmented Reality and Virtual Reality in education and viewed it as a possible addition for excursions and experiencing things in real life.

The semi-structured interviews with students centered on visiting places and seeing things otherwise not accessible to them. For example, it was suggested that one could try to fly a rocket into space and explore the planets.

The teacher explained that students had difficulty understanding the Solar System and its structure, particularly

Students were also curious of finding out how various planets responded to water. Guiding question was figuring out what would happen with water on Mars or the moon?

The shift in perspective brought about visualizations where Earth is seen from the moon thereby not only learning about the moon, but also how Earth looks from a distance.



A visualization of the making of a meteor crater. How does it happen and what is the relationship between meteors and craters? All intended for virtual reality (VR).

Visit and explore the Solar System's various planets. Students proposed designing the ability of jumping from one planet to the next.

Students also compared the sizes of the planets in the Solar System. Also discussing distances, movement through space, and planetary rotations.

TABLE 1. Physical prototypes.

the distances between the sun and the planets and their proportions relative to each other, as well as planetary motion through space. The teacher believed Augmented Reality could remedy this learning challenge.

Both students and teachers were interested in working with Augmented Reality and participated in the participatory design process. Based on the teacher's opinion about problems with spatial understanding of the Solar System, it was decided to continue to work on this topic.

FIRST DESIGN ITERATION: PHYSICAL PROTOTYPES AND LUNAR PHASES

The first design iteration with students and teacher consisted of prototyping and discussing design possibilities.

Physical prototypes: in class, we conducted a joint prototyping. The students were told that the theme for the prototyping was "The Solar System," which they had studied for a few weeks in science lessons. They should visualize what had been difficult to understand about the Solar System and how Augmented Reality and Virtual Reality might make it easier.

They had a wide range of materials available, such as cardboard, various types of paper, glitter, glue, markers, crayons, modelling clay and Styrofoam balls of different sizes.

The students divided themselves into groups and started discussing and designing. The students received feedback during the development of the prototypes based on planet sizes, rotations, and distances including shifting perspective from the earth to other planets along. We also discussed meteors and their impact on planets surfaces. The general idea was to figure out what would be suited for the augmented reality application. The results are shown in Table 1.

Design reflections on physical prototypes as part of the learning process

The students' development of physical prototypes, in the form of 3D globes of modelling clay in combination with drawings, illustrated their understanding of the Solar System and what they wished to be implemented and visualized in Augmented Reality.

The prototypes helped students to visualize planetary size ratios and develop insight into the conditions of rotation of planetary orbits around the sun and other planets (Moon) as well as their rotation about their own axes. It became apparent that some of the students had problems with spatial understanding and with planets rotating around each other. This exemplifies Shelton & Hedley's (2002) description of the spatial learning problem. In addition, the planetary movements promoted the understanding of the temporal aspects of planetary rotations and their orbits, and thereby an understanding of the rhythms of day and night, lunar phases, and what constitutes a year.

Furthermore, the prototypes invited a change of perspective, such as to stand on the moon looking at the earth, or to become an astronaut and travel between planets.

From the children's prototypes and the school's science textbooks (Veje, 1997; Veje, 1998; Hansen et al., 1994) and curriculum, and in collaboration with the teacher, we selected a number of key elements, which corresponded well with visualizing spatial sizes, relationship, and movements.

The key elements:

- Earth in relation to Moon and Sun
- Earth's tilt and its implications for day and night lengths and seasons
- Moon phases
- Change of perspective: user standing on the moon and watching the earth
- The entire Solar System: the planets relative to each other and facts about them
- Constellations
- Meteors and comets
- Space (satellites and man in space).

We decided to focus the first high-fidelity prototype on the relation between Earth and Moon. Here we could focus on both perspectives (rotation and planet sizes) inspired by the children's physical prototypes and their understanding of planet sizes. It was also a manageable starting point for the technical development. We postponed the creation or exploration of a meteor creator and space to a later point, as we found it was more suited to a Virtual Reality experience.

Reflections on AR as a lens

According to the explorative study and first iteration phase, students wanted to experience the creation of a meteor

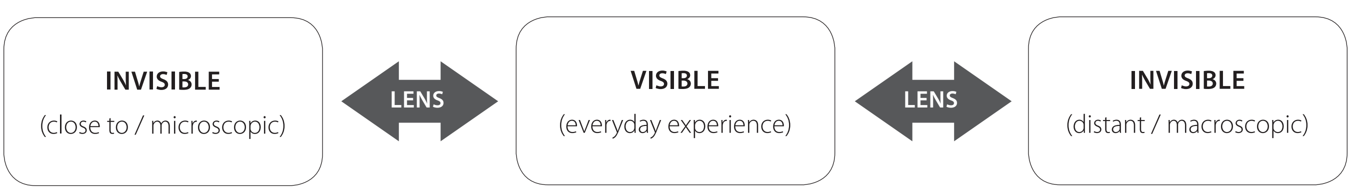


FIGURE 5. Augmented Reality as a lens for the microscopic and macroscopic.

FIGURE 6. Student looking in the science book with Google Cardboard and seeing an augmented moon.

crater, travel between planets or stand on the moon. They wanted to experience rare phenomena and distant objects from new perspectives that lay beyond everyday experiences. Dunleavy (2014) described how the design affordances of Augmented Reality can act as a lens, allowing pupils to access views and elements of the environment that otherwise lie beyond everyday experience (see Figure 5).

The critical and unique design metaphor for Augmented Reality is therefore understood as the lens rather than the screen. This is where students can observe and interact with levels of reality which otherwise are geographically distant and outside the range of everyday experience.

SECOND DESIGN ITERATION: TESTING OF FIRST VERSION OF AUGMENTED REALITY APPLICATION

The students tested the first version of the application that used a page in the students' science book as an AR enabler. This resulted in a realistic and rotating Moon in 3D, generated on top of the image in the textbook (Veje & Christensen, 1997).

Results: The students expressed enthusiasm for the augmented Moon in the textbook. Several tried to reach out and touch the moon (see Figure 6). One of them reported it felt like being flown to the moon without being an astronaut. Others recognized augmented reality as close to normal everyday tangible experiences as seen in Figure 6 where a student tried reach out and touch the projected content in this case the moon. These examples highlight the experiences with Augmented Reality as intense and lifelike. In this way, the students gained experiences of the Solar System that they otherwise could not possibly have experienced first-hand in the real world (Kerawalla, Luckin, Seljeflot, & Woolard, 2006). This follows Kolb (1984) when he emphasized concrete experiences as key ingredients in learning processes. It underscores the design affordances of Augmented Reality as technology that can bring distant things near and make the unseen seen. It is technology that gives rise to observations and experiences, which open the formation of abstract concepts and reflections on them. In order to promote reflection and conceptualization teachers, however, play a significant role.

Reflections on Using the Original Textbook

The images in the textbook were not optimized for image-based Augmented Reality. Sometimes it was too difficult for the children to enable the moon simulation. It was decided to develop a compendium, an abbreviated textbook comprised of our own text and pictures in this case the solar system, in order to prioritize easy camera readings of the special image-tags: a process that would require ongoing adjustments. It was a big decision, because the development of our own learning material requires much time and a specific technical, scientific and didactic knowledge. The teacher spoke in favor of development of a compendium, since it would integrate the Augmented Reality application well (Hansen et al., 1994). The teacher agreed to use the new compendium as part of the project.

THIRD DESIGN ITERATION: TESTING OF SECOND DIGITAL VERSION AND FIRST VERSION OF LEARNING COMPENDIUM

We decided to focus on the relationship between the earth and the moon in order to visualize the moon's phases on our own compendium: a topic that is difficult to comprehend from 2D drawings and text. Figure 7 shows the moon's rotation around the earth, and how the relationship between Sun, Earth, and Moon affects the phases of the moon. We had to work with the shadow on the earth to teach the students that it meant night-time. The moon phase application was linked to pictures and explanatory text in the compendium. Additionally, the other planets were visualized individually.

The students tested the prepared compendium and the application in groups. They started browsing through the compendium and subsequently tried out the simulation of the phases of the moon and planets. Finally, we concluded with an open interview about their experience with simulations and what they thought of the new material as well as their own science technology book.

Results: During the prototype test, it was clear that the students had problems understanding the basics of the Solar System. For example, several of the students found it difficult to find out the size ratio of Sun to Earth. Several believed that all the planets were the same size (perhaps because all the planets on the posters in the classroom all were of equal size). A few students even thought that the moon was bigger than the earth. It was also difficult for the students to interpret the shadows on the moon.

FIGURE 7. The application with the phases of the moon seen through Google Cardboard. Distance and size ratio of the globes is not correct in the first version.

The students liked the digital prototype even though we didn't use the correct distances between Sun, Earth, and Moon. The reason was that the distances are so great that it would be difficult to observe them in the same Augmented Reality view.

Moreover, it was clear that the compendium visualized information about how and where Google Cardboard was active.

Student reactions to the first design of the compendium were positive. They said it was "cool" to be able to look up information easily, for example about Mars. This information was located in the same place, whereas their own book was "... more like a narrative and pell-mell." Especially, pages with the various planets were highlighted because they were set up in a form that presented them at a glance (see Figure 8). The students added that they would like the compendium to be more colorful without becoming too childish—an idea we worked with in the third iteration (see Figure 8).

When students browsed further in the compendium and tested other visualizations of planets, there was no indication of when the cardboard and application could be used, and the interaction with the compendium did not fully work. It was difficult to figure out where exactly to place your hand in order to make the 3D representations of the planet shift. It also was not clear how the planets changed—from which planet to the next. This was due to both technical and design difficulties.

The user experience could be improved. For example, it should be clear to students when and where to use Google Cardboard as shown in Figure 9. They should have information on which planet they have chosen, and the choice should be accompanied by affirmative feedback. In addition, the compendium should specify when the proportions and distances were approximated facts without being properly scaled. These are all suggestions for future improvements.

Reflections on technology maturity in relation to design.

Unity3D in combination with Vuforia worked better with the homemade textbook. The students' Augmented Reality experience was highly dependent on the smartphone used, particularly if the phone's resolution was not sufficiently high. This caused problems in the more complex visualizations containing several planets.

FIGURE 8. Testing of augmented reality in relation to the compendium.

DAG OG NAT

Solen søger for vi har nat og dag på Jorden. Jorden roterer om sig selv. Det tager 24 timer. På den side af Jorden, der vender væk fra Solen er det nat og på den side, der vender mod solen er det dag.

Earth Axis
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
Sun rays

Derfor er det nat for folk i Australien, når det er dag for os i Danmark og omvendt når jorden har drejet en halv omgang som sig selv. Det er også grunden til man har indført tidszoner. En tidszone er et område på jorden, hvor klokken altid er det samme. Det gør det muligt for alle at stå op til solopgang og gå i seng til solnedgang.

OG KORTE OG LANGE NÆTTER

ÅRSTIDER

Jordens akse, som den roterer omkring, har en hældning på 23,5 grader. Det gør at vi, her i Danmark, om vinteren får mindre sollys end om sommeren. Det er derfor dagenes længde varierer og vi om vinteren kan synes, det er mørk hele tiden.

North Pole
South Pole

Pga. jordens hældning vil den nordlige halvkugle være heldet mod Solen den ene halvdel af året, og væk fra Solen den anden halvdel af året. Når den nordlige halvkugle peger væk fra Solen vil Solen ikke stå så højt på himlen. Derfor har vi den korteste dag på dette tidspunkt. Den kaldes for vintersolhverv og ligger omkring d. 21. december. Når den nordlige halvkugle derimod peger mod solen, står solen højt på himlen og vi har sommersolhverv.
Det er omkring d. 21. juni.

Det er også grunden til at vi har årstider. Pga. af hældningen skiftes den nordlige og sydlige halvkugle til at pege mod solen i løbet af Jordens tur omkring Solen.

4

DE FORSKELLIGE PLANETER I VORES SOLSYSTEM

MERKUR

Merkur er den mindste planet og den, der ligger tættest på Solen. Den har ingen måne og ligner månen, da den har kraterfyldte områder og plane sletter. Merkur har ingen atmosfære og derfor er der intet til at holde på varmen om natten. Det gør at temperaturen kan svinge mellem 450 grader om dagen og -170 om natten. Den manglende atmosfære gør også at der ikke er noget vejr på Merkur; det blæser eller regner aldrig. Himlen er altid skyfri, men til gengæld helt sort både om natten og dagen.

VENUS

Venus har næsten samme størrelse som Jorden. Dens atmosfære er næsten 90 gange tættere end Jordens og har en høj koncentration af drivhusgasser, mest kuldioxid. Det gør Venus til den varmeste planet i solsystemet med en temperatur på over 400 grader.

JORDEN

Jorden er den eneste planet, så vidt vi ved, hvor der er liv. Jordens atmosfære adskiller sig væsentligt fra de andre planeters, da den grundet tilstedeværelsen af levende organismer, indeholder 21 procent ilt. Pga. Jordens placering i forhold til Solen er temperaturen lige tilpas til at Jorden kan have en atmosfære og flydende vand på overfladen.

BRUG BRILLERNE TIL AT SE DE FORSKELLIGE PLANETER TÆT PÅ.
HOLD HÅNDEN OVER DEN PLAENET DU VIL SE

8

FIGURE 9. Section of the compendium version 2.

FOURTH ITERATION: FURTHER DEVELOPMENT OF THE COMPENDIUM AND APPLICATION

In the fourth design and test round, students and teachers tested the improved version of the compendium and application (see Figure 9).

We had implemented colorful backgrounds in the compendium, to make it even easier for the application to read pictures and to support the students' design ideas of preferring colors. We added a Google Cardboard icon, indicating where to access the augmented content (see Figure 9) in the lower right corner. In the right-hand corner, a description of the augmented content was added, with a note that the proportions were approximate. Table 2 shows screen dumps of the augmented content.

Feedback from the Teacher on the Compendium Version 2

In the compendium review by the teacher, she thought that the front had improved: "The layout looks exciting. Just by looking at the front, you quickly get an idea of what the material contains." The introduction, she believed, gave a good overview and gave the teacher the courage to embark on using Google Cardboard in class.

She did mention, however, that some pages were too compressed for some students. It might help to make the text boxes less transparent.

She suggested adding a paragraph about people in space, e.g., the first Dane in space, Andreas Mogensen, about whom the students had talked a lot.

The teacher also requested some kind of assignments, in which students could apply their knowledge. In addition to their science / technology book, the students have a task booklet in which they use what they have learned. She suggested small quizzes, such as one in which the students would guess from a picture or small game whether the moon was waxing or waning.

The students reviewed the compendium individually. They suggested improvements to the application both regarding the appearance and content of the compendium and different parts of the application, and—not least—whether they had understood the importance of the new icon indicating usage of Augmented Reality.

During the process, we discovered that 11 out of 12 students were surprised by the size ratios between Sun, Earth and Moon, particularly the size of the sun compared to the earth. They thought the earth was bigger and the sun was smaller.

The students pointed out that the application sometimes "froze"—e.g., the planet would stop spinning and start again after a little while. Especially, the pages with three planets had a tendency to "freeze". The application also "froze" when students changed the distance between them and the compendium while the application was running.

On the positive side, the AR enabling in the compendium generally worked better and more smoothly, compared to the AR enabling in the old textbook.

Design Reflections and Unintended Mislearning

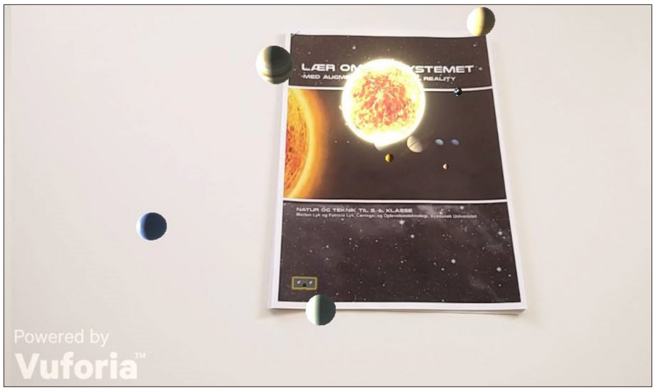
In the third iteration, Earth and Moon proportions and distances were incorrectly scaled and inadequately portrayed. The relative sizes were corrected in the fourth iteration. Such conditions can lead to mislearning. "Mislearning is about learning that does not correspond to the intended or what have been communicated as to content" (Illeris, 2006, p. 158). This is very unfortunate, as we experienced that some of the students had gotten the wrong impression of the planets and the sun's aspect ratio—most likely from the posters in the classroom.

In the compendium, we made notes when augmentation did not reproduce the correct proportions or distances, but we were not certain that the students would read this. We considered and discussed placing the information within the application, but we finally decided it belonged in the compendium because it would most likely disturb the augmented reality experience. Despite this, in the fourth iteration, most students were surprised at how big the sun was compared to the planets in the Solar System (see Table 2; size ratio of planets in Solar System, including the sun on the left). This demonstrates that, in spite of design approximations, Augmented Reality technology enabled experiences that imparted a nearly correct perception of the sun and the earth's mutual proportions which correlated well with the learning goals.

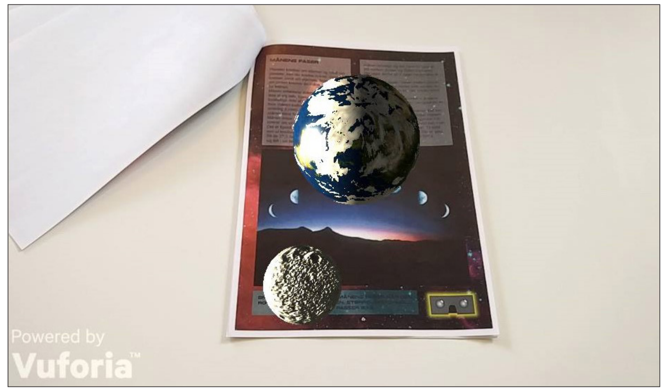
Design Reflections on Understanding Spatial Objects and Movements in Three Dimensions

From a design perspective, there is no doubt that Augmented Reality is well suited to design visualizations of spatial objects and their movements unfolding in time and space. Perhaps it was not difficult for the students to understand the spherical shape, as it is well known from balls and oranges and so on. However, it was difficult to fully understand how the planets rotated around their own axis and moved around each other in three dimensions, even with approximated size and distances. This was highlighted in the 3D applications of the planets in orbit, the moon's orbit around the earth, the earth's orbit around the sun, size ratios and the sun in relation to its planets (see Table 2).

The design affordances of Augmented Reality enable understanding of spatial objects and how they move in time, pointing to a possible solution to the spatial learning

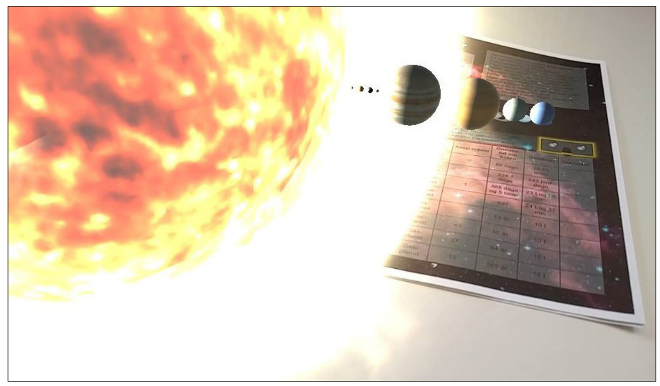


Solar System—planets in orbit around the sun (front side of the compendium).



Moon-to-Earth size ratio as well as the moon's rotation an orbit around the earth.

Earth and Moon's rotation and orbit around the sun (distance and scale incorrect).



Size ratio of all the planets in Solar System – including the sun on the left (distance incorrect but size ratio correct).

Visualization of Mars including rotation.

Visualization of Uranus including rotation.

TABLE 2. Augmented content of the planets and the Solar System v2.

problem described by Martín-Gutiérrez et al. (2009) and Cheng & Tsai (2012). This of course makes the design affordances of augmented reality well suited in conjunction with digital learning applications.

Augmented Reality design possibilities point not only to visualizing the three spatial dimensions (length, width, height), but also to the temporal dimension (time; see Figure 10). In Augmented Reality, we visualize where and when events occur. This is possible not only for macroscopic objects such as the Solar System, but also for microscopic objects including atoms and cells and the complexity involved in their mutual dynamics.

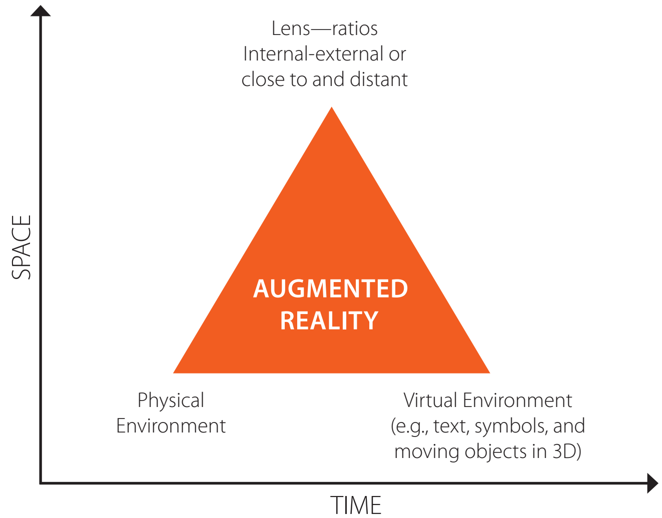


FIGURE 10. Augmented Reality design affordances open up possibilities to augment events in time and space that lie beyond the normal perceptual system (illustrated by the coordinate system). Augmented Reality design space consists of three variables: virtual objects, physical surroundings, and the lens with which to view the world (illustrated with a triangle).

Reflection on learning design as a method

If we had simply applied existing applications, the students would have been users but not co-designers in a joint design process (Druin, 2002) with several stakeholders: researcher, teacher and students. The students' active participation in the design process and design decisions placed them in the role both of informants and stakeholders, since they provided valuable input and feedback for both the compendium and application. They could therefore see their contribution throughout the process.

The design process expanded students' understanding of the Solar System through tactile realization via prototyping of the Solar System elements (Sun, planets and moons). It also gave them insight into how a design process is shaped and run, and a sense of how learning material (compendium and application) is created through the design process and decisions. It offered them an experience of influencing the design process and its outcome. The students felt "empowered" (Druin, 2002, p. 21) while the adults listened to them and took their opinions seriously. Furthermore, the design process served as an active knowledge environment where knowledge was situated through a contextualized activity as a function of interactivity (Barab & Roth, 2006). From observations, semi-structured informal evaluative interviews during iterations in the design process, and the teachers' assessment, we found that building physical prototypes of the solar system enhanced the students' knowledge and understanding of the structure and complexities of the solar system as well as gaining insights to the design process.

Overall, the design process outlined was an affordance network, where students were given more options to achieve learning objectives. "An affordance network is the collection of facts, concepts, tools, methods, practices, agendas, commitments, and even people, taken with respect to an individual, that are distributed across time and space and are viewed as necessary for the satisfaction of particular goal sets" (Barab & Roth, 2006, p. 5). In our case, the affordance network comprised the compendium, the Augmented Reality design space, the learning design method, the teaching practice in class, etc. In the design process, the students increased the opportunities to act both as co-creators and as users. Thereby they increased their learning horizons and life world (Barab & Roth, 2006).

SUMMARY AND CONCLUSION

This article has described the design affordances of Augmented Reality and the design processes intended to support learning processes for Danish 6th grade students.

The design process began with testing existing Augmented Reality applications, after which physical prototypes were developed of globe scenarios comprising planetary size, rotation around its own axis and its orbit. This helped to inform the design space of the educational planetary application. Students participated as informants, testers, and co-designers in the design process.

In summary, Augmented Reality as a design space for designing learning applications addressing the spatial learning problem was suitable for our design goals:

- to make the useable seen
- to bring the distant near
- for visualization of size ratios, distances and behavior
- to scale either the macroscopic down or the microscopic up, so both aspect ratios are available for a learning experience
- to illustrate the temporal relationships between objects
- to simulate spatial objects over time
- to shift perspectives so that objects can be seen from new perspectives, such as standing on the moon and looking at the earth
- to display objects in three dimensions, whether under macro- or microscopic conditions.

We learned that, as designers of Augmented Reality learning applications, we should make our own materials (e.g., a compendium) in order to make image-based Augmented Reality work properly in daily school practice. The images needed to be optimized for Augmented Reality. We also demonstrated that Augmented Reality afforded design addressing the spatial learning problem, which is of particular interest when designing learning applications for these kinds of educational needs.

PERSPECTIVES

It could be interesting to include 3D camera functions in the design space, since they add to the catalog of design affordances when addressing the spatial learning problem; we would expect them to make the experiences even more authentic. This could also give students the opportunity to record their own material, so they could design their own learning material, thereby expanding the design space of Augmented Reality to other subject matter, such as studies of mammals, dinosaurs and diving under water to visit otherwise inaccessible places on the deep-sea floor or visiting faraway cities in, for example, geography teaching.

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