2016 IEEE International Symposium on Mixed and Augmented Reality Adjunct Proceedings

Participatory Design of STEM Education AR Experiences for Heterogeneous Student Groups: Exploring Dimensions of Tangibility, Simulation, and Interaction

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ABSTRACT

In this paper, we present the results of a multi-year participatory design process exploring the space of educational AR experiences for STEM education targeted at students of various ages and abilities. Our participants included teachers, students (ages five to fourteen), educational technology experts, game designers, and HCI researchers. The work was informed by state educational curriculum guidelines. The activities included developing a set of design dimensions which guided our ideation process, iteratively designing, building, and evaluating six prototypes with our stakeholders, and collecting our observations regarding the use of AR STEM applications by target students.

Keywords: Augmented Reality, Collaborative Design, Education, Handheld AR, K-12.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; H.5.2 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities

1 INTRODUCTION

Augmented reality (AR) presentations of educational content has been shown to be effective and compelling in a diverse set of applications: from a biological system that used zippers and augmented reality to allow you to open up a "human body" [7] to augmented storybooks [3] and tools that assist the intellectually disabled in education [5]. These and other applications have been shown to facilitate collaborations through students in related learning scenarios [3]. However, designing successful educational interventions requires diverse expertise (e.g. teachers, technologists, artists, students etc.) and can be difficult to deploy in the field[15]. There are still many open research questions regarding: the design of AR interfaces for children, how to transform curriculum into effective AR experiences, how to tune the experience for different age and ability ranges, how to design for collaborative learning, and how to consider the practicalities of the classroom in the formative stages of design. With the goal of continuing to work on these challenging research questions, we engaged in a two-year participatory design process with a team of teachers, students, educational technology experts, computer scientists, and game designers to explore the design space of AR STEM education games. In this paper we present the research contributions of this exercise including:

- A formalized discussion of the dimensions of a collaborative AR education application
- Discussion of six prototype AR education systems spanning the design space, informed by state elementary school curriculum guidelines
- The results of multiple participatory design sessions with students age 5-14 and teachers
- Initial *design observations* regarding the design of AR education applications

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2 MOTIVATION FOR PARTICIPATORY DESIGN

The initial motivation of this work was to continue to explore the value AR can bring to STEM education, creating "personalized lenses" that overlaid age and ability specific virtual content on physical environments, making the experience accessible to various ages, capabilities, and knowledge levels. We also believed that collaboration would be a key aspect to explore due to the established value AR can bring to collaboration [10], the realities of the classroom environment, and the potential of multi-age/ability learner groups.

Our goal was to iteratively design AR prototypes, initially, based on state STEM curriculae, spanning a range of dimensions related to the virtual/physical continuum, interaction types, and educational pedagogy, refined via a participatory design process with students and teachers. We also planned to use a variety of techniques, artifacts (with and without technology), and AR prototypes to guide the process over many sessions ("Participatory design can be implemented in many ways, including workshops, ethnography, cooperative prototyping, mock-ups, card sorting, and user design"[8]). Participatory design has proven itself fruitful multiple times in previous studies. While developing an augmented reality book for deaf students Zainuddin et al. found participatory design revealed potential problems with their design that the researchers would not have anticipated [17]. When used in an application to help with dementia, participatory design was valuable in the ideation phase and caregivers were consulted during the prototyping phases. However, the researchers regretted not involving their users more significantly in the prototyping phase [13]. And Van Mechelen et al. created a checklist to inform participations and to negotiate values with child-design partners [14]. Therefore, our goal was to include our participants (both adults and children) throughout the ideation, design, prototyping, and re-design process guided by a pre-defined protocol (later sessions were guided by more controlled user studyesque protocols than a typical formative informal design activity). We also endeavored for participation in this project to provide a valuable educational experience for our child participants [4].

3 BACKGROUND RESEARCH

The first step of this project was to understand the educational requirements of early learning classes and to collect insights into the typical environment and daily functioning of an elementary school classroom. As such, we engaged with an expert who was a former teacher, director of technology in a school, and former Board of Education member and analysed the scientific and mathematical curriculum for each grade in the state of Georgia,

978-1-5090-3740-7/16 $31.00 © 2016 IEEE
DOI 10.1109/ISMAR-Adjunct.2016.31

guided by our educational expert [2]. She provided this early guidance as well as serving as a participant and advisor throughout the project.

4 IDEATION

At this stage, our goal was to think formally about the potential design space for our applications, informed by the background research. Via ideation sessions with teachers and students we explored questions of which aspects of the experience should be physical and which should be virtual, which types of interaction (both tangible and virtual) to explore, and how to embed the scientific method into the experience. This process resulted in a set of dimensions of application design that we used to guide our prototype planning to ensure that they explored the potential design space adequately:

Tangibility. The dimension of tangibility is meant to capture how important the user interaction with physical props is to the AR experience. This dimension can span from simply having a printed marker for tracking, to having a few markers used as a tangible user interface (TUI), to having a prop's physical state tightly controlling an AR simulation.

Educational Experience Type. The dimension of educational experience type describes how an artifact would be incorporated into a lesson or experiment. For instance, a dangerous chemical experiment could be replicated in AR via a highly virtual *simulation* controlled by a TUI, or an *illustrative* augmentation could provide a 3D diagram accompanying educational text. Alternatively, the virtual content could augment a purely physical experiment (e.g. measuring the friction of objects sliding down an inclined plane) that the students are engaged in, providing additional educational content as a *situated visualization*. The augmentations can also be used for *verification*, used during or following an experiment or calculation, to confirm their work.

Game elements. This dimension captures the degree to which formal game elements (e.g. rules, procedure, win condition, reward structure etc.) and theming are integrated into the experience.

Collaborative,multi-user support. Different interface and experience designs will be more or less viable for multiple users. As such, the dimension of multi-user support is an important factor to consider. Some activities may be more rewarding with a group or difficult for a single user to execute, while for others additional users create distraction, frustration, or an asymmetric educational experience.

Level of abstraction of representation. For different levels of education, different levels of abstraction may be required. For example, for a younger student audience cartoon characters may act out a complex concept such as the effect of friction, while for older students the experience presents them with mathematical formulae. This dimension of design conveys how in-depth, technically accurate, and specific the descriptions and representations of concepts are.

5 THE ARTIFACTS

In the course of this project we developed six prototypes via the participatory design process (all were written in the Unity3D game engine, used the Vuforia toolkit for tracking, and were deployed on a series of iPads). Versions of each were used as artifacts during the design sessions and subsequently re-designed as a result the process. We had three artifacts generated before our first collaborative design session with children, and generated a fourth for our second set of sessions. After the sessions were complete, we generated two additional artifacts taking considerations from our student and teacher feedback. The following chart catalogues the six artifacts and their design dimensions. The design progression of each is described in detail in the next section.

Table 1: Artifacts as they apply to various design dimensions

Artifact	Tangibility	Education Type	Game Elements	Multi-user support	Level of Abstraction
Cube	Augments tangible objects	Illustrative	No game mechanic	Single user	Almost no Abstraction
Train	Multiple tangible parts. No tangible input.	Experiment Verification	Story, step-by-step process	Shared physical space	Moderate Abstraction
Catapult	Base are as well as target controllers	Simulated Physics	Win condition	Potential for multiple users	Stylized Simulation
Laser	Trackers for base map and controller objects	Simulated Physics	Multiple levels, clear goal, win condition	Designed with multiple users in mind	Light Abstraction
Planes and Screws	Augments the pencil sharpener	Illustrative	No game mechanic	Single user	Varied Abstraction
Circuit Diagram	Base area and target controllers	Experiment Verification	No game mechanic	Can have multiple users	Light Abstraction

5.1 Measuring Volume and Density (Cube)

The physical cube has a trackable pattern on its six faces (see Fig. 1). Initially, augmentations added virtual lines on each axes to denote length, width, and height, and labelled with measurements for each dimension.

Figure 1: Initial cube wrapped in an AR target.

In our second iteration we placed a virtual skin on the cube that looked like a crate, and added a sign floating above the cube that illustrated how to calculate volume and density.

Before we did our first student evaluation, we added in a second object. We then added a purely virtual experience on the device where a character would explain how volume was calculated through a sequence of tap-through dialogue, and a step-by-step display of the length, width, and height being calculated, and then explain how to calculate volume and density (see Fig. 2). In doing so we added in a goal of determining which of the objects was less dense. After the first evaluation, we realized that this extra content made the experience tedious and we returned to a more succinct version.

Figure 2: Additional explanatory "game" content from iteration three.

5.2 Understanding Force (Train)

The initial idea for the Train artifact was to make a program that would assist in the setup of an experiment. It had a base trackable mat which would display step-by-step virtual outlines of where to place the tracks. This was a prototype that would lead into another experiment.

In the second iteration of the program, there is a small frame target on the train itself, as well as another that sits on the ground. A physical spring-based launcher is placed at one end of the tracks. The application guides the user to place the train in front of the launcher. When the train is launched, it tracks distance from the train to a set point on the base, and says if the distance was enough or not. The train itself issues smoke from its smokestack while it is in view.

In the third iteration of the train, more animations were added as well as a narrative. The object of the program at this point was to re-adjust the position of the train and launcher, as the distance launched should be fixed for the most part, teaching about forces.

After the initial study, we found that children would take too much time in setting up the tracks, and decided to remove the initial placement of the train tracks and piston from the process. We removed a majority of the narrative and modified the game objective. A second tangible marker was then used by user to input their prediction about how far the train would travel down the track after being launched (see Fig 3).

Figure 3: Final iteration of the Train Artifact.

5.3 Angles, Projectiles and Simple Machines (Catapult)

A wooden catapult sat on top of a large mat with a trackable image on it. A small frame target on the arm of the catapult was used to track the angle at which the arm is being held. In early versions of the catapult artifact the augmentations provided situated visualizations to help the student understand how the angle of release would affect the distance the projectile would travel (see Fig. 4(a)). In the second iteration, an abstraction of the units of force was added to the display as a way to further explain forces to the students (see Fig 4 (b)).

Figure 4: (a) Initial Catapult demo (b) Alternate version of the catapult demo, including the use of Newtons in the measurement.

In the third iteration of the Catapult Artifact, a small virtual catapult appeared on the screen next to the actual catapult, and virtual bandits appear on the screen (see Fig. 5). The real catapult was used as a controller for the virtual catapult, which would fire a small virtual rock, controlled by the game physics engine. The game objective is to hit the bandits with the catapult.

Figure 5: Simulated catapult aiming to fire at the "bandit".

5.4 Optics (Laser)

The Laser Artifact was created after the first set of participatory design occurred, and was informed by our results in these sessions. It uses a large colorful map as an image target, as well as some frame targets with different colors on them that create a TUI. The augmentations populate the map with virtual game content. In one corner, a bandit appears. In the other corner is a wizard with a stationary laser beam. Virtual walls appear on the map that will block the beam. The frame targets represent either mirrors or prisms, which virtually appear above them. Mirrors reflect the beam based off of how they are angled, and prisms will bend and redirect the beam. The object of the game is to make the beam hit the bandit (See Fig. 6). Once the bandit is hit, the walls will change position and the beam must be redirected again.

Figure 6: Laser Artifact. Red tiles act as prisms, blue tiles as mirrors.

5.5 Planes and Screws (Pencil Sharpener)

This situated visualization prototype was implemented after both sets of participatory design sessions occurred. Informed by the design process with the cube demo, it allowed the student to have "x-ray vision" into the inner workings of the machine (a manual and an automatic pencil sharpener). We used this demo to explore levels of abstraction. Younger students would see a lumberjack using an axe to cut at pencils inserted into the sharpener (see Fig. 7 (a)), while older students saw an exact representation of the inner workings of the machine (see Fig. 7 (b)). When the device got closer to the pencil sharpener, the representation would switch to a more detailed cut-away visualization.

Figure 7: (a) A cartoon lumberjack sharpens a pencil inside a real sharpener (b) the 3D content used for the augmentations in the version designed for older students

5.6 Electricity (Circuits)

This final artifact was also generated after both sets of participatory design sessions, and was more informed by the laser prototype. We created a large grid that functions as an AR target large enough to be the base, and has smaller targets that can be placed inside to represent transistors, diodes, and other electrical components. Once a connection is made, the program simulates the current flow for the constructed device (see Fig. 8). This object could be used in high school labs as a low cost alternative to electronics kits, and could be augmented easily with a worksheet asking for students to draw diagrams that would create various flows of current.

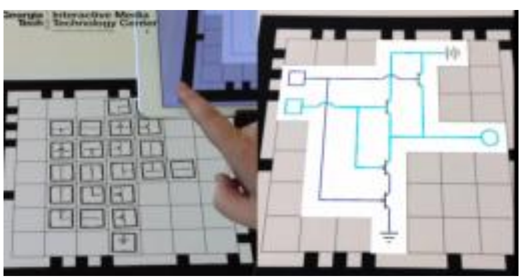

Figure 8: Student uses a TUI to control a circuit simulation.

6 Participatory Design Sessions

We held three rounds of formal participatory design activities. The first involved two sessions with our prototype, one was a duo (a 5 year-old boy and a 9 year-old girl), and the other with an 11 year-old girl. After these sessions, we revised our designs, making significant design changes and/or creating an entirely new artifact. Our next set of design sessions involved seven sessions with groups of students ranging from ages 6 to 14. Our third set of design sessions were three formal interviews with different teachers from diverse schools.

6.1 Initial Student Evaluation Sessions

6.1.1 Study Setup

We had two sets of participatory design sessions. Our first session was with a group of 2 children: a 9 year old girl, and a 5 and a half year old boy. A second session included an 11-year-old girl. In both sessions, we had a researcher leading the children through the cube, train, and catapult artifacts in that order, along with a fantasy narrative connecting the three experiences together. As the participants progressed, they were asked a series of questions to check understanding of the material, as well as what they found easy and what they found difficult.

6.1.2 Student Reactions

None of the children had prior experience with augmented reality, but seemed to gain an understanding of it through the cube artifact. During the train task, the two children took turns holding the tablet. The two worked together to place the train tracks, and communicated instructions to each other well. The children enjoyed the physical aspects of the demo (placing the train, pressing the physical button to launch the train), and were able to understand the concepts of how weight and momentum affected how far the train would travel. When using the catapult demo, the children struggled to keep the tablet which negatively impacted tracking performance. They also said that it was hard to see the screen when holding the catapult, and as a result, they had to work together to accomplish the desired result. Though they understood the concepts, the controls made it difficult to aim the catapult. All this being said, they still reported enjoying the catapult task, and that they liked the extra characters around the catapult.

The lone student found the train task difficult to complete on her own, as she was holding the tablet in one hand and reaching to place things with the other hand. She felt the instructions were confusing and went too fast. The catapult task was extremely difficult to complete with one person due to holding the tablet steady and pulling the catapult's arm back at the same time.

6.2 Secondary Student Evaluation Sessions

After these two sessions we spent three months updating our artifacts with the new information that we had gathered, as well as creating the laser artifact utilizing the lessons we had learned in creating the other three artifacts.

6.2.1 Study Setup

We ran seven sessions, with students from ages 6 to 14 participating. In total, we had 10 boys and 7 girls. Each session contained students of varying ages. We had 4 sessions of 2 participants, 1 session of 5 participants, 1 session of 3 participants, and 1 session of one participant. In these sessions, we had set up a small physical area in the lab as an "education space", meant to be comfortable and inviting for children. The seating and tables were more suited to children, being at a lower height. There were also various decorations around the space, which proved to be distracting to disinterested participants when the study was actually running.

The protocol involved the participants experiencing the artifacts (the cube, the train, the catapult, and then the laser). No fantasy narrative was used in this version, and each of the artifacts were presented as a standalone experience. During the process the participants were encouraged to think aloud and after each demo, the participants were asked in-depth questions about their experience.

6.2.2 Student Reactions

The participants reacted positively to most of the programs, and understood the potential educational value: "*It's used to teach you and do it for you instead of the textbook*" (referring to the cube artifact).

Many of the participants had a desire to see customization added to these artifacts. When referring to the cube artifact, one participant said "*Is there a way I could get the app with the blocks and make our own blocks*?" When referring to the laser artifact, one participant suggested, "*What if every time you got a level, you had more options to choose more space things or that you get options to the same board with the same obstacles, just a different setting. Almost like choosing your character*."

The children reacted positively to the train experience and the AR content. However, they had problems following the step-by-step instruction, even though they had already been reduced as a result of previous feedback.

During use of the laser prototype, participants interactions indicated that they came to view the laser artifact as more of a game than a learning tool, and repeatedly requested additional game content. They asked us to make it more of a challenge with more varied content/levels. The participants suggested adding in a timer, with different difficulties of the task, as well as more variation in the levels, "*the walls would shift, but the bandit would stay in the same place*." We also received suggestions of making different maps, such as ones with volcanoes or a beach, for greater replayability.

The game elements and level of abstraction of the laser prototype also negatively impacted the educational aspect of the experience. One participant said, "*So the laser can't go through the trees? It can't shrink the trees? It's like an obstacle*", referring to how bushes that popped up acted as an obstacle instead of an object as expected.

We also received varied responses regarding which artifact was preferred. The response hinged on whether they preferred the experience to be free-form versus more structured or realistic versus game-like ("*I liked how you had to complete it* [laser]. *It was more like a game. There was stuff you had to complete. Something to work towards*.")

6.2.3 Student Behaviors

While performing the study, the larger groups tended to be more distracted, possibly due to a lack of defined roles. When there were only two participants in a session, it was easy for both to be able to see the screen and work, and roles could be more easily established ad-hoc. In the group of five, there were times where participants seemed to be sitting out because they could not see the mobile device or the table, so we occasionally prompted them switch roles. The students who were holding the mobile device naturally took a leadership role (similar to [11]). They tended to be more likely to give directions and show the others where to move objects. This was most prevalent in the laser artifact, where turning the physical tiles to direct the beam was an important part of the exercise. In the train prototype, older children made a point to let the younger participants have a turn, often running through multiple times so everyone got a turn. In the laser prototype, we observed older children starting out as the "foreman," controlling the device, but the younger children lacked the dexterity to manipulate the TUI and/or misunderstood the optical properties of the game elements. As a result, eventually the older participant would hand the device to the younger child to hold, while the older manipulated the tangible elements (see Fig. 9).

Interestingly, we observed on multiple occasions, participants pressing on the tablet screen in an attempt move or activate a physical object.

The tracking in the catapult demo required that the small frame targets on the physical machine be in view along with the underlying mat. This was too physically and cognitively (i.e. they did not have a correct mental model of how the tracking worked) demanding for younger children. After running a few sessions we found their frustration derailed the design session and decided to remove it from the protocol.

After seeing a number of students tire of holding the device steady over time, we added in an external flexible mount that could hold the device steady to help alleviate the strain on the participants. This was particularly helpful in our sessions with a single student, as it allowed them to avoid the trouble of having reduced multiple-hand coordination [12].

Figure 9: Two participants interact with the laser prototype

6.3 Teacher Interviews/Design Sessions

We interviewed three teachers from three separate schools to garner their feedback on our prototypes and overall project. There were a few commonalities that came up in each interview. All of them intuited that the activities would be best for groups of three students, and that any more children than that would cause lead to conflict and chaos. They all also hypothesized that by adding worksheets to the less structured artifacts (e.g. the train and the cube), the experiences would be more effective.

The cube was seen as a good way of introducing concepts, or reinforcing concepts for visual thinkers, but not as a full on activity on its own. The teachers thought it could be used as verification for the students after they had done a traditional activity first.

All of the teachers were concerned about the safety of the students. They saw ways for students to misuse most of the small physical components of the artifacts. For instance, they envisioned that the plunger used to propel the train could cause injury. Similarly, they were concerned about the use of the toy catapult (even though it is marketed as an educational toy for the classroom) in the school environment.

7 Design Observations

After doing the final design sessions, we have condensed our findings into six categories of design observations.

7.1 Practical Issues for Deployment

In order to keep students engaged, long series of instructions should be avoided. As such, an additional teacher is required. It is acceptable to have a small information panel to pop up at the start of the program, but a key/guide could also be physically printed on the trackable mat. Alternatively, teachers who we interviewed suggested using worksheets alongside the programs to help teach the students effectively and to test the student's understanding during the use of the program.

Another issue for deployment comes in the form of the materials required. In order for the program to be easily deployable, objects common to classroom spaces should be considered in AR tools to make them easily deployable, either by using elements universal to that environment (e.g. blocks), or by basing it on printable elements that can be distributable digitally.

7.2 Designing for Group Interaction

After testing the artifacts with groups from sizes two to five, we determined that the optimal group size for AR applications is 2-3 participants per device, with one person holding the tablet and giving directions, with the other two working. A group of more than three leads to an unnecessary amount of distractions, as well as participants feeling left out. The teachers that we interviewed also said that these would be the ideal group sizes for the AR artifacts.

As expected, in mixed groups, the older students tended to take more active roles in the groups, and the younger students tended to follow the directions of the older students. However, there seemed to be few negative consequences from this.

The children often began the experience fighting over control of the tablet and over who got to move objects. However, over time they became more cooperative with each other, using deictic gestures to show where to move TUI elements, referring to landmarks on the printed mats, and giving short commands to each other. The critical thinking role was often taken by the student holding the tablet, and the ones who were moving the TUI elements would ask for direction.

7.3 Designing for the Distractions of the Classroom

Younger children can often be easily distracted, and as such, you must make sure that your AR program is engaging enough to get the point across without being overstimulating. In our prototypes this was accomplished through virtual characters in the scene, that captured the children's' interest. We also found the physical environment had to be staged such that distracting elements that you might typically find in a research lab were at a minimum. During our participatory design sessions, we also received feedback that the goal of each experience should be made clear to increase enjoyment and eliminate frustration. Feedback indicated that this was done effectively in the laser demo, where the instructions were short and there was a clear end goal.

7.4 The Pros and Cons of Tangible Props

By utilizing trackable tangible props can produce an engaging and novel interaction experience. We used these methods in our laser and catapult artifacts with a level of success. We found the children to be consistently engaged, though occasionally frustrated. The issue with using props and the image-based tracking as controls is that it requires the user to maintain a camera angle that captures the relationship between a base marker and the markers on the TUI elements.

However, we found it was possible to overuse tangible props, leading to distraction for younger users. There were many instances in our testing phases when the children would grab a tangible object and start playing with it without even looking at it through the AR lens.

Along these same lines, it is easy for tangible props to lead children into assuming that other objects in the environment can control the AR experience. For instance, in the cube demo, the children tried to examine other elements in the environment to see if the AR lens would alter them. Similarly, some children were confused about whether they were supposed to interact with a real-world object through the tablet or through physical interaction; hence the observed phenomenon of participants expecting to affect real-world objects by interacting with their image on the tablet screen.

7.5 Physical and Cognitive Capabilities and Limitations of Children using AR

During the sessions, it was clear that students could not hold the tablet for long periods of time (as shown in [12]). As such, groups of three emerged as an ideal group size since the team could share the duties of holding and interacting with the device. We also found that for this audience the program should not have long sections of instructions since this resulted in high memorization and attention span requirements.

Another important and yet simple constraint when designing for younger users was that they are generally much shorter than adult users. As such, making sure that the AR program does not require a high or wide viewing angle is important, unless it can be guaranteed that the physical targets will be on the ground or a very low table. As such, the user physical capabilities should be taken into account when considering the natural viewing angle[16].

7.6 Amenability of Various STEM Topics to AR

Physics education is a promising application of AR and VR technologies. Others have explored the use of AR for physics education including augmented physics textbooks [6], the visualization of forces on a pendulum and falling objects [1], and PhysicsPlayground (a sophisticated toolkit for constructing virtual mechanics experiments and observing them in AR [9]).

We saw this echoed in the feedback to our prototypes from students and teachers. The teachers believed that these programs would be effective supplements to their lessons, and would help with students who could not grasp certain concepts based on lectures alone. We believe it is important to include the teachers form the beginning of the design process to identify which topics are appropriate for AR treatment.

8 Conclusion

Over the period of two years we worked closely with stakeholders to explore AR STEM education applications via participatory design activities. The outcomes included developing a set of design dimensions to guide our ideation process, iteratively designing, building, and evaluating six prototypes with our stakeholders, and collecting our observations regarding the use of AR STEM applications by children ages five to fourteen. We plan to use this experience to guide the creation of more significant educational AR interventions that can be deployed at a large scale to a diverse population of students.

References

[1] *Augmented Reality Physics Education Tool: Inredar*. 2011 2011; Available from: http://www.youtube.com/watch?v=GzGV1WuC9kc.

[2] *Georgia Department of Education Frameworks*. 2015 2015; Available from: https://www.georgiastandards.org/Frameworks/Pages/BrowseFrameworks/ScienceK-5.aspx.

[3] Billinghurst, M. and A. Duenser, *Augmented Reality in the Classroom*. 2012. **45**: p. 56-63.

[4] Bower, M., et al., *Augmented Reality in Education – Cases, Places and Potentials*. 2014. **51**: p. 1-15.

[5] Colpani, R. and M.R.P. Homem. *An innovative augmented reality educational framework with gamification to assist the learning process of children with intellectual disabilities*. 2015.

[6] Dünser, A., et al. *Creating Interactive Physics Education Books with Augmented Reality*. 2012. ACM.

[7] Juan, C., F. Beatrice, and J. Cano, *An Augmented Reality System for Learning the Interior of the Human Body*. 2008: p. 186-188.

[8] Kang, M., P. Choo, and C.E. Watters, *Design for Experiencing: Participatory Design Approach with Multidisciplinary Perspectives*. Procedia-Social and Behavioral Sciences, 2015. **174**: p. 830–833.

[9] Kauffman, H. and B. Meyer. *Simulating Educational Physical Experiments in Augmented Reality*. in *SIGGRAPH ASIA*. 2008. ACM.

[10] Kaufmann, H. and D. Schmalstieg, *Mathematics and geometry education with collaborative augmented reality*. Computers & Graphics, 2003. **27**(3): p. 339-345.

[11] Morrison, A., et al., *Like bees around the hive: a comparative study of a mobile augmented reality map*, in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 2009, ACM: Boston, MA, USA. p. 1889-1898.

[12] Radu, I. and B. Macintyre, *Using children's developmental psychology to guide augmented-reality design and usability*. 2012: p. 227-236.

[13] Slegers, K., A. Wilkinson, and N. Hendriks. *Active Collaboration in Healthcare Design: Participatory Design to Develop a Dementia Care App*. 2013. ACM.

[14] Van Mechelen, M., et al. *Applying the CHECk Tool to Participatory Design Sessions with Children*. 2014. ACM.

[15] Vate-U-Lan, P., *Augmented Reality 3D pop-up children book: Instructional design for hybrid learning*. 2011: p. 95-100.

[16] Xu, Y., et al., *Pre-patterns for designing embodied interactions in handheld augmented reality games*. 2011: p. 19-28.

[17] Zainuddin, N.M.M., H.B. Zaman, and A. Ahmad. *A Participatory Design in Developing Prototype an Augmented Reality Book for Deaf Students*. 2010.