Creating Interactive Physics Education Books with Augmented Reality

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ABSTRACT
Augmented Books show three-dimensional animated educational content and provide a means for students to interact with this content in an engaging learning experience. In this paper we present a framework for creating educational Augmented Reality (AR) books that overlay virtual content over real book pages. The framework features support for certain types of user interaction, model and texture animations, and an enhanced marker design suitable for educational books. Three books teaching electromagnetism concepts were created with this framework. To evaluate the effectiveness in helping students learn, we conducted a small pilot study with ten secondary school students, studying electromagnetism concepts using the three books. Half of the group used the books with the diagrams augmented, while the other half used the books without augmentation. Participants completed a pre-test, a test after the learning session and a retention test administered 1 month later. Results suggest that AR has potential to be effective in teaching complex 3D concepts.

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Augmented Reality, Augmented Book, Interaction, Authoring, Education, Learning, Electromagnetism

ACM Classification Keywords
H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems – Artificial, augmented, and virtual realities

INTRODUCTION

Augmented Reality (AR) seamlessly merges real-world environments with computer-generated objects (Azuma, 1997). It allows users to experience these objects and interact with them in a very natural way. AR is beginning to emerge as a promising tool in educational settings. Although AR has existed in the mainstream for some time, it only just begun to be used in schools (Billinghurst & Dünser, 2012).

AR promises to aid task-related learning through providing visual and interactive experiences that allow in-depth understanding of complex phenomena (Shelton & Hedley, 2004). Educational AR applications can help to present and communicate abstract concepts to students and simulate dynamic processes that may not be visible in real life. In this way AR can offer advantages over other forms of teaching for spatially complex topics.

AR affords interactivity that offers potential for both learning and for assessment, as objects that could be too large or small in reality can be adjusted for situated learning (Johnson, Smith, Willis, Levine, & Haywood, 2011). Interactivity in AR also provide avenues for constructivist learning, whereby users help develop their own understanding of concepts based on self-directed learning (Tobias & Duffy, 2009). AR has been shown to assist the development of spatial abilities and provide cognitive advantages for learning when compared to traditional, 2D displays (Shelton & Hedley, 2004).

One emerging application of AR in education is an augmented book. Billinghurst introduced the MagicBook (Billinghurst, Kato, & Poupyrev, 2001), an application that overlays virtual 3D content on top of book pages and allows users to seamlessly move into a fully immersive Virtual Reality (VR) environment. The potential of using digitally augmented books has caught the attention of researchers and educators. Augmented books provide a means for enhancing regular 2D books with interactive visualisations, animations, 3D graphics and audio. The purpose of adding such features is to create engaging user experiences and to enrich the reading experience.

A very important feature of augmented books is that they allow the user to interact with the virtual content. Interaction can enhance the learning experience by allowing users to actively explore and manipulate the content (Dünser & Hornecker, 2007). Basic interaction is provided by manipulating the book. Rotating or tilting the book pages shows virtual content from different positions and angles, and flipping book pages changes the virtual content displayed. These interaction techniques are afforded by the physical implementation of an AR book and are also often the only interaction techniques offered to AR book readers. Very few books have additional features and many offer very limited interactivity.

We have developed a simple AR framework to provide a method of creating interactive educational AR books. Using this framework we have created three AR books to study the effectiveness of AR for teaching Electromagnetism at the mid high-school level. This is a topic dealing with rather complex 3D concepts that cannot be easily observed or displayed by physical objects. It also is a subject area which many students struggle to grasp (Chasteen & Pollock, 2009). The books are structured and contain content (text and diagrams) similar to standard high school textbooks. It was

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hypothesised that textbooks with AR would be more effective learning tools than traditional textbooks for understanding these 3D concepts. Therefore participants who studied content from an AR book should perform better in tests than participants who studied from a traditional book.

In the next section we present related work. We later describe the technologies used to create our framework and present the design and results of a pilot study to investigate the effectiveness of using an AR book for teaching complex 3D concepts. We conclude with a discussion of the results, limitations and the potential for further work.

RELATED WORK

Our work is based on earlier work in education, interactive technologies and augmented reality. In this section we review related work from each of these areas and explain our research contribution.

Interactive technologies enable the creation of immersive experiences that allow users to perform actions impossible in the real world (Dede, 2009). Liarokapis et al. (Liarokapis, Petridis, Lister, & White, 2002) argue that AR systems must enable users to interact with the 3D information in a natural way, akin to real world interaction. Multimodality and interactivity have been shown to increase engagement, immersion, and support learning. Moreno and Mayer (Moreno & Mayer, 2005) argue that interactivity can promote learning by activating certain cognitive processes. Prior knowledge stored in long-term memory may be activated, organized and integrated with the incoming information. In a study Moreno et al. (Moreno, Mayer, Spires, & Lester, 2001) found that students who are allowed to interact can remember more and transfer what they have learned to new problems better than students who only passively receive information. The students work harder to make sense of the material and rate their interest higher.

Grasset et al. (Raphaël Grasset, Dünser, & Billinghurst, 2008) explored the design space of a mixed reality book and discussed different interaction techniques. Gaze interaction allows users to interact by looking at the book content, finger interaction consists of pointing at parts of the book, and tangible interaction involves positioning or moving a tangible element for interaction. Shelton and Hedley (Shelton & Hedley, 2004) argue that interactive AR provides cognitive advantages for learning compared with traditional desktop 2D interfaces due to advanced possibilities for spatial visualization. Although direct effects of training with an AR-based geometry education application on spatial ability could not be found (Dünser, Kaufmann, Steinbügl, & Glück, 2006), this might be due to standard assessment instruments not being sensitive enough for measuring abilities used in actual 3D environments.

Despite the relatively large amount of research in the area of augmented reality, most studies focus on the technical aspects of AR (Dünser, Grasset, & Billinghurst, 2008). Although more recent studies have addressed education, few have targeted secondary school level subjects or include interactions with the content.

Dünser and Hornecker (Dünser & Hornecker, 2007) concluded that letting children interact with an interactive AR story book may not only be very engaging but also could facilitate recall of story events. A later study compared good and low ability readers (Dünser, 2008). The storybooks used in this study featured text-based material and interactive AR sequences in which students used handheld paddles for interacting with the content. They found that low ability readers remembered significantly less information from the text-based material. However, for material from interactive AR sequences there was no difference in recall performance between the two groups. Therefore AR books that allow interactive engagement with content could support students who have problems with the predominantly text-based learning materials found in education today.

There is great potential for AR books to be used in higher education (Johnson et al., 2011) as well. AR has been used to teach geometry (Kaufmann & Dünser, 2007), Newtonian physics (Buchanan, Seichter, Billinghurst, & Grasset, 2008), earth-sun relationships (Shelton, 2002), language (Liu, 2009) and human biology (Vilkoniene, 2009). Having AR books means that all that is required of a school is a webcam, computer and some simple software. This is one of the great advantages of AR books, as it makes them easily accessible and usable by schools all around the world.

One reason why AR books are not yet very prevalent in classrooms is the relative difficulty for non-experts to create them (Billinghurst & Dünser, 2012). Developing AR books still requires highly specialised skills such as 3D programming and modelling. AR authoring tools enable creating AR experiences without programming knowledge (Seichter, Looser, & Billinghurst, 2008) (Hampshire et al., 2006) (MacIntyre, Gandy, Dow, & Bolter, 2004). Such tools allow teachers and students to create simple AR scenes, however, few support integrating interaction. Building AR books can be an educational experience in itself, since students must think about how to use the technology to represent complex concepts. Creating such learning material requires students learn about and get an understanding of the content. Developing content is an engaging creative experience that can impart practical 3D design skills and problem solving (Billinghurst & Dünser, 2012).

As can be seen, earlier research has shown the potential for AR books in education, but there has been little research on the type of tools for creating such books, or formal evaluation in a high school setting. Given these limitations, our work makes the following novel contributions:

- We present a framework for making the process of creating educational AR books easier and faster

- In a pilot study we investigate whether an AR book created with this framework could be an effective learning aid in high school settings

- We compare how students learn complex three dimensional concepts using an AR book to learning from a traditional book.

THE EDUCATIONAL AR BOOK FRAMEWORK

In order to make it easier to develop AR books we created a generic software framework. The software was written in C++ and designed to run on Windows operating systems. This section provides an overview of the key components to create an AR application: viewpoint tracking, graphics rendering, interactivity, and scene creation.

Viewpoint Tracking

Viewpoint tracking is needed to calculate the position of the user's camera relative to the AR book pages, and then use this to overlay the virtual graphics in the AR view with the correct perspective. For tracking, the framework uses the ARToolKit (Kato & Billinghurst, 1999) computer vision library for finding the pose of markers on the book pages. The markers can be used as visual elements on the pages to make them more suitable for an educational book. ARToolKit was therefore adapted to be flexible enough to allow each marker image to double as a diagram, where the addition of a 5 mm thick black border around the diagram is all that is needed. Figure 1 shows an example of the tracking markers on the book page.

Graphics Rendering

Graphics rendering was provided by the OpenSceneGraph (OSG) scene graph library, which defines a 3D scene as a graph of different types of nodes. This was used in our framework to render and manipulate the 3D content. The system is configured by loading a configuration file at run-time. The main purpose of the configuration file, an example is shown in Table 1, is to quickly and easily define the pages and page characteristics that the book will contain.

Table 1. Example configuration file

```
markerDir = "markers/";
modelDir = "models/";
camWidth = 800;
camHeight = 600;
book = {
   pages = (
      {
         type = "SelectablePage";
         scenes = (
            {
               @include "marker_b1p1-1.cfg"
               @include "model_repellingMags.cfg"
            },
            {
               @include "marker_b1p1-2.cfg"
               @include "model_attractingMags.cfg"
            }
         );
      },
      {
         scenes = (
            {
               @include "marker_b1p2-1.cfg"
               @include "model_singleMagField.cfg"
            }
         );
      }
   );
};
```

Each page has an optional 'type' referring to its behaviour and a list of scenes. Each scene has a single 'marker' and 3D 'model' defined. The preferred method is to write separate configuration files defining the markers and models, so that they can be reused on different pages. 'Marker' defines the pattern file to be used and the dimensions of the marker. 'Model' defines the model to be used and optionally a translation, rotation and scaling to apply. To allow texture animations the texture files and the nodes of the model that the textures are applied to must be specified in this file, and to allow model animations the animated nodes must be specified.

Interactivity

To add interactive behaviour to a page, the user can choose one of the built-in interactions or create their own, by extending the Page class. Built in interaction can be specified in the configuration file. One example is 'SelectablePage'. With this type of page users can switch the scene displayed on the page. Only one of the scenes present on the page will display at once. When the user touches one of the markers and pulls their finger away, the second scene becomes active. Extra parameters can be added to custom typed pages, so when users define custom interactions they can add other fields in the page definition.

Other built in interactions are 'PlayablePage' allowing an animated scene to be played and paused by touching a marker designated as the play button, and 'SwitchablePage' allowing a switch node in a scene to be toggled by the user. This for example could be used to change between two animations or toggle the visibility of parts of the scene.

The latter two interactions allow the user to create custom behaviours through creating animations or switch nodes in the modelling program they are using, so that users with modelling experience but no programming experience can create custom behaviours.

Scene Creation

In addition to providing tracking, rendering and interactivity there is a need to create the AR scenes that will be shown on the pages of the book. The process for creating a scene consists of creating the 3D content in a 3D modelling program and then exporting it to one of the formats compatible with OSG. Key-frame animation can be used to add animations to the scene from within the modelling software. By default, this animation will continuously loop. To control the playback, the animated node must be specified in the configuration file. To create texture animations, the node and all of the textures that will be cycled through must be specified.

THE AR BOOK

Using this framework three books were developed to teach concepts of magnetism. The content was based on Level 2 NCEA Physics material taught in New Zealand secondary schools[1]. The books were designed so that on each page there was both text and diagrams, each covering approximately half the page respectively.

The main focus of the first book was to introduce students to magnets, starting with magnetic forces (attraction and repulsion), covering magnetic field lines and induced magnetism and finishing with application to the earth's magnetic field and the use of compasses. Each topic had a page with a corresponding diagram that also was used as a tracking marker for the AR book (see Figure 1).

In the second book, electromagnetism is introduced. The magnetic field caused by a current in a straight wire is explained, including the Right Hand Grip convention (Figure 2). The affect on the magnetic field of forming a loop from the wire is shown, followed by the explanation of a solenoid.

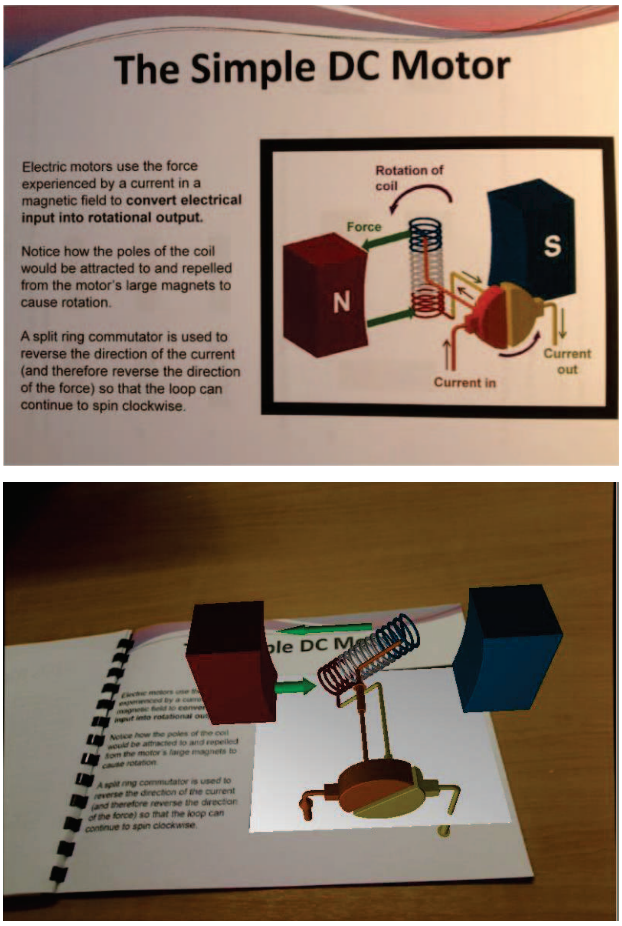


Figure 1: Top: Text and diagram explaining a simple DC motor in Electromagnetism book 3; Bottom: Animated 3D model of the motor a displayed in the AR book.

In the third book, the force on a current-carrying wire resulting from intersecting a magnetic field is introduced, including the Right Hand Slap convention. The idea of using electrical energy to produce mechanical motion is presented, and the purpose of split ring commutators is explained. Finally, the concepts are combined to explain how a simple DC motor works (see Figure 1).

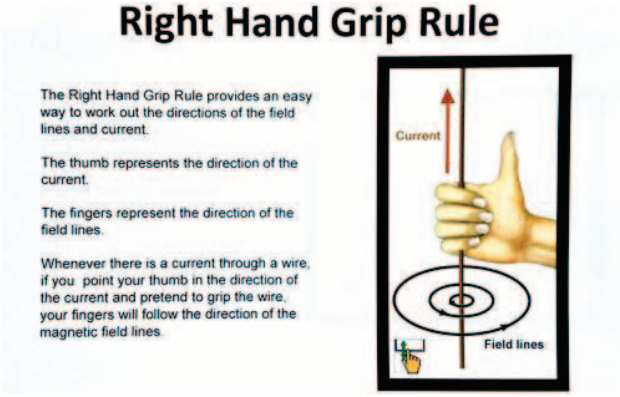


Figure 2 Right Hand Grip Rule

The provided 'SelectablePage' interaction is used, along with an interaction where the user picks up a 'magnet' (tracked cardboard paddle shown in Figure 3) to magnetise and move a virtual nail[2]. Animated models are used, where magnets attract and repel according to their polarities. Animated textures display arrows moving along magnetic field lines, reinforcing the convention of field lines running from the North Pole to the South Pole.

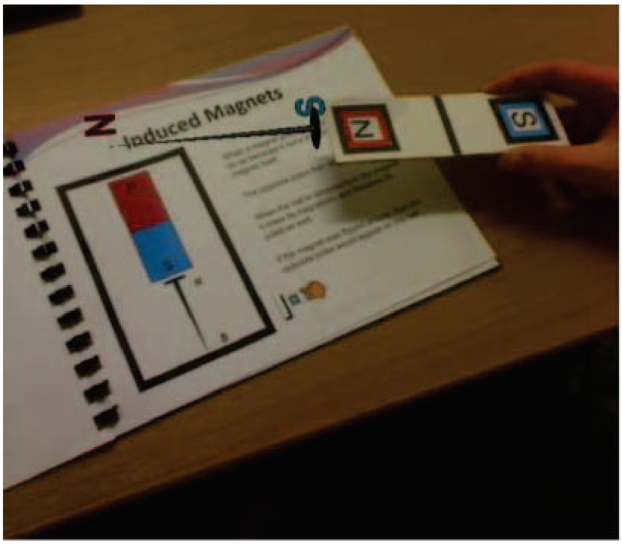


Figure 3: Induced Magnets pages show with AR and magnet paddle with AR nail

Small 'interaction symbols' were included on the pages represented by a small hand pointing to the black border (see Figure 4). This allowed the user to distinguish those images with interactions from those without. On pages with more than one marker, a user could select the desired image and start an animation by placing a finger over the black border of the marker and removing it again ('SelectablePage' interaction). In addition to this, some AR markers had interactions that allowed the participants to change the direction of particular components of the

[1] New Zealand Qualifications Authority (2011). Physics Subject Resources. Retrieved from: http://www.nzqa.govt.nz/qualificati-onsstandards/qualifications/ncea/subjects/physics/levels/

[2] This is an example of a specific, not build in interaction. Such more specific interactions can be created and added to the framework.

model, for example reversing the direction of the current in a wire ('SwitchablePage' interaction).

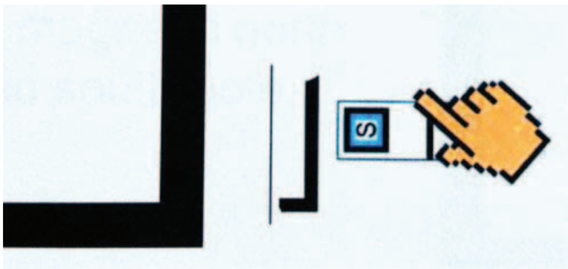


Figure 4: Interaction symbol used to indicate that readers can interact with the content.

The books are designed to be viewed using a handheld AR device (Raphael Grasset, Dünser, & Billinghurst, 2007) connected to the PC, as shown in Figure 5. This display incorporates a Logitech Quickcam Pro for Notebooks webcam (2.0-megapixel sensor, Carl Zeiss optics) and two SVGA LCD screens with 800x600 pixel resolution, allowing the user to view the scene in a direct natural manner.

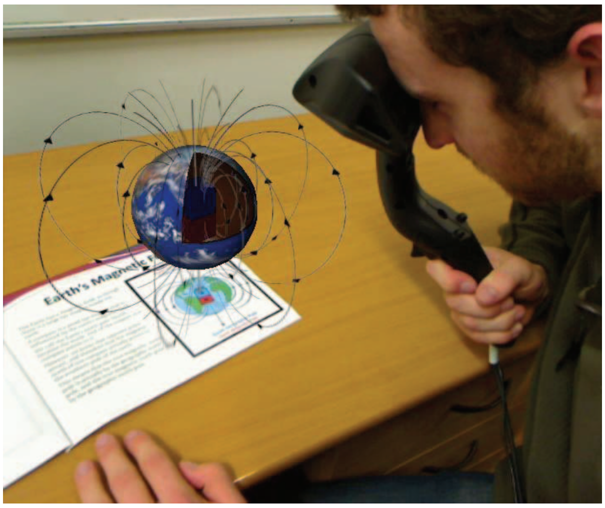


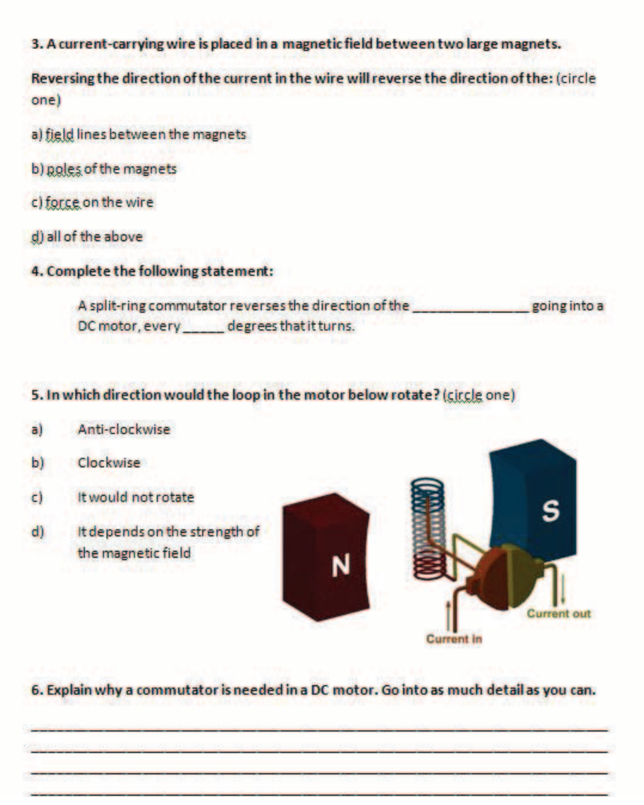
Figure 5: User holding the AR handheld device to view the AR scene.

STUDY DESIGN AND PROCEDURE

Once the AR books were developed and approval from the University Human Ethics Committee granted we conducted a user study to compare learning with an AR book to learning with a traditional book. A between groups design was used and participants were randomly assigned into one of two conditions. Both groups used the same books providing text and illustrations that doubled as AR tracking markers. The Non-Augmented Reality (NAR) thus was reading and viewing a regular book with text and illustrations whereas the AR group used the same books but with AR content overlaid onto the illustrations. The AR group received instruction in how to use the technology. They also were encouraged to look at the 2D images in addition to the AR images.

The study was split into three sessions, covering one book at a time. Each participant took part in all three sessions across seven days. Each session was at least one day after the previous session, that is, no more than one book was studied by a participant each day, but was no more than three days after a previous session. There was no other teaching. The participants had five, six and seven minutes to study each of the three books, one, two and three, respectively. Participants were informed when their study time was half-way through, and when there was one minute remaining, and were encouraged to keep reading through the book until the time was up.

Understanding of the learned concepts was measured through a set of three tests. This set of tests was given as a pre-test, a test following each of the three learning sessions, and as a retention test. Participants had six, seven or eight minutes to complete the three tests respectively, in the pretest, mid-test and retention test sessions. Participants were told when their time was half way through, and when there was one minute remaining. All participants were given the same amount of time to complete the tests. These tests only covered content that was presented in the books. Some questions tested recall whereas others were inferential and required an in-depth understanding of the electromagnetism concepts gained through the book content. See Figure 6 for an example of the test questions. The tests were only static images, no AR was used in the test material.



3. A current-carrying wire is placed in a magnetic field between two large magnets.

Reversing the direction of the current in the wire will reverse the direction of the: (circle one)

a) field lines between the magnets

b) poles of the magnets

c) force on the wire

d) all of the above

4. Complete the following statement:

A split-ring commutator reverses the direction of the ______________ going into a DC motor, every _____ degrees that it turns.

5. In which direction would the loop in the motor below rotate? (circle one)

a) Anti-clockwise

b) Clockwise

c) It would not rotate

d) It depends on the strength of the magnetic field

6. Explain why a commutator is needed in a DC motor. Go into as much detail as you can.

____
____
____
____

Figure 6 An example of Test 3, questions 3 to 6

Four weeks following the final study session, a retention test took place. This test was made up of the same questions as the pre-test. It had a total of 31 questions totaling 34 marks. Responses to these questions were marked against the same marking schedule as the previous tests.

Participants

Ten female secondary school aged students from Year 10 (aged 13 to 15 years) participated in the study along with their science teacher. All attended a New Zealand private school for girls. The sessions took place in the school's science resource rooms.

RESULTS

Due to the small number of participants we decided to analyse the results descriptively rather than using inferential statistics. The two conditions were compared in two steps. Firstly, responses to the pre-test, mid-tests and retention tests were marked and recorded for both groups. Average scores for each group in each test were calculated and compared using percentages. Secondly, the number of correct responses for each individual question in the tests were also recorded (as percentages) in order to identify specific questions where there may have been distinct differences present between the two groups.

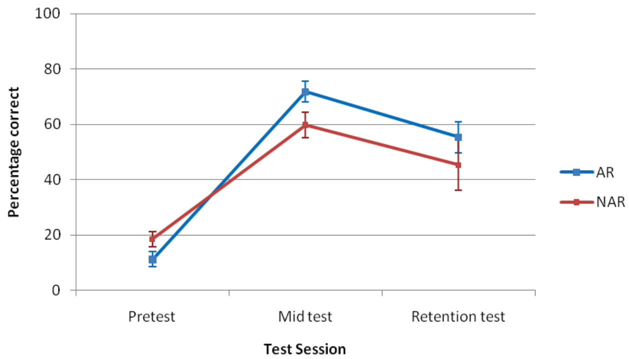


Figure 7: Average percentage of correct questions for the AR group and NAR group across three testing sessions.

Figure 7 shows the average percentage of correct questions for both the AR group (n=5) and the NAR group (n=5) across the pre-test, mid-test and retention test. As can be seen the test scores were higher for both the AR and NAR groups after they had used the educational books, showing that learning has taken place.

The NAR group scored slightly higher on average in the pre-test, with an average score of 18.5% (SD 6.1%) compared with the AR group's score of 11.2% (SD 6.0%). The AR group's average score was 12.1% higher than the NAR group's score in the mid-test, with a mean score of 71.8% (S.D. 8.4%) for the AR group compared to 59.7% (SD 10.3%) for the NAR group. In the retention test, both groups scores fell approximately equally compared to the mid-test scores. This left the AR group's scores higher than the NAR group in the retention test on average, with a mean score of 55.3% (SD 12.4%) compared to the NAR groups' score of 45.3% (SD 20.4%). These results indicate a trend in favour of the AR condition, in that the AR participants overtook the NAR group and scored higher on average in the mid and retention tests.

Figure 8 shows the percentage of participants in each condition who answered each of the retention test questions correctly. The detailed analysis of the questions showed that the AR did better on questions that required drawing field lines on a magnet (e.g question 2a, see figure 8), questions relating to the right hand rule (questions 1 and 3a), and questions on drawing field lines (4b and 6). No NAR students correctly answered questions requiring determining the direction of force on a diagram (2c, 2d, 2e), determining in which direction a loop in a motor will rotate (5) and a question asking "Explain why a commutator is needed in a DC motor" (question 6).

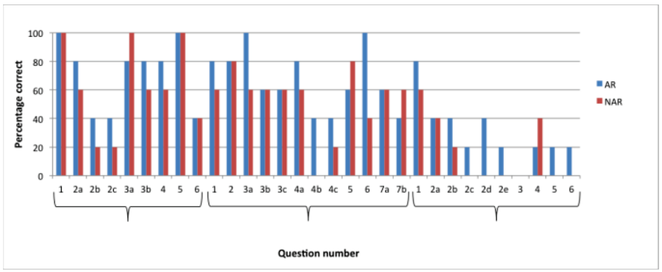


Figure 8: Percentage of participants in the AR and NAR conditions who correctly answered each question in Retention tests.

Participants using the AR books appeared much more eager at the beginning of each session compared with the NAR group. After the completion of the study, participants in the NAR group had the opportunity to interact with and experience the AR books. All participants leapt at the opportunity to do so, and spent considerable time "free-playing" with the content. The physics teacher of the students was also impressed with the content and saw great potential for AR books to be used in classrooms and aid learning in a positive way.

DISCUSSION

This pilot study sought to identify whether AR books created with our AR book framework could be effective in helping students learn complex, three dimensional electromagnetism concepts. It was hypothesized that the AR books would be effective learning tools for understanding these 3D concepts, and that participants who studied content with these books would perform better on average in tests than those participants who studied from traditional books containing the same content and depictions of 3D in a traditional book illustration. No comparison was made with animated diagrams in 2D (refer to Figure 2 as an example). The results support the hypothesis, and suggest that Augmented Reality has some potential to be effective in aiding the learning of 3D concepts. We have found a consistent trend visible for the two groups, with the AR group scoring higher on average in both the mid-tests and retention tests. This supports the notion that AR books can help in learning complex three dimensional concepts, although the small number of participants (n=10) in our study does not allow us to test the hypothesis statistically in a meaningful way.

There has been little research on the effect of AR on learning, however this study supports the idea proposed in many previous studies that AR has potential to be more effective in learning complex three dimensional concepts than traditional learning methods (Dünser, 2008; Dünser, Kaufmann, Steinbügl, & Glück, 2006; Johnson et. al., 2011). Previous studies have discussed possibilities of AR assisting the development spatial abilities (Shelton & Hedley, 2004), and could therefore be contributing to the differences observed between the two groups.

The interactivity afforded by AR books provides great potential for learning and an advantage over traditional books or other learning media. Tangible interaction using tools such as the magnet paddle and augmented nail with labeled poles allow for a learning experience that combines real world objects with virtual content. Together this can contribute to a deeper understanding. Interactions in AR engage learners with the content, and allow for knowledge to be acquired through their own manipulation of content (Dünser, 2008), as supported by constructivist learning theory (Tobias & Duffy, 2009).

Analysing responses to individual questions can help to highlight differences and similarities between the two conditions. Only one participant in each group correctly answered a question in Test Three which required inferential understanding. Content that was presented to the students through animated 3D models and interaction in the AR book e.g. using the magnet paddle was comprehended better by the AR group. The same content was presented to the NAR group through static images. This indicates that 3D animation and interaction helps students to learn related concepts. Other questions where the AR group did better on average tended to be those that required more explanation or thorough understanding of complex concepts to answer correctly, suggesting that the AR group did better on the more difficult content.

In the retention tests, performance dropped below mid test levels indicating a loss of information, though trend lines for each group remained parallel, and therefore do not point to a difference in retention due to condition differences, this suggests that the loss of the information was due to natural memory loss over time.

The largest limitation in this experiment is that it is a pilot study with only ten participants. The differences observed between the groups could potentially be due to other factors than the conditions tested in our study. Another important point is that the tests for both groups were the same; in that, all figures in the tests were presented as two dimensional drawings. It is possible that differences between the groups may have been larger had the images in the test questions been presented three dimensionally using AR. Two dimensional diagrams may have lead to misunderstandings of the questions when in reality, participants could have understood the concepts but not their 2D representations. There is reason to assume that skills trained in AR cannot sensibly be tested with standard paper-pencil based tests (Dünser, 2005).

This study used handheld AR devices for the AR condition, which were very effective in removing mirror effects such as those observed in previous AR studies (Dünser, 2008). One of the promising aspects of AR books in educational settings is the idea that all that is needed is a webcam, a computer, and the printed book. However, using just a webcam does not present quite the same experience as the handheld device. The webcam would be held in the hand and images would be viewed on the computer screen instead of above the book where they would otherwise be looking. This has the potential to change with the development of specialised glasses or goggles for AR (Rosenblum, 2000), however, these may take time to become affordable in school settings.

CONCLUSION AND FUTURE WORK

Our results are consistent with findings of the impact of technology on learning in previous studies, showing a small to moderate difference between computer aided learning and traditional, non-computer aided learning (Tamim, Bernard, Borokhovski, Abrami, & Schmid, 2011). The results support the hypothesis, suggesting that AR books have some potential to be effective in aiding the learning of complex spatial concepts. However, our initial results have to be corroborated with a larger sample. If future studies continue to show similar results for learning using AR, introducing AR technology into schools holds great potential for future learning.

The AR book framework has been found to be a successful tool for developing effective educational books. Thus the framework is a step towards providing a tool for streamlining AR book creation. Currently, users can create a new book with three built in interactions by changing the configuration files. While the built in interactions might seem limited, they already do allow creating quite powerful effects for educational books such as switching scenes or triggering, stopping or changing animations (e.g. changing current in wires). But the addition of more advanced animation and interaction capabilities certainly would allow the creation of richer educational experiences.

While no programming is required, the current system, which requires editing a configuration file, still might seem relatively technical to some users. Some form of What You See Is What You Get (WYSIWYG) editor most likely would cater for a bigger audience.

REFERENCES

Azuma, R. T. (1997). A Survey of Augmented Reality. *Presence - Teleoperators and Virtual Environments, 6*(4), 355-385.

Billinghurst, M., & Dünser, A. (2012). Augmented Reality in the Classroom. *IEEE Computer, 99*.

Billinghurst, M., Kato, H., & Poupyrev, I. (2001). The MagicBook: a transitional AR interface. *Computers & Graphics, 25*(5), 745-753.

Buchanan, P., Seichter, H., Billinghurst, M., & Grasset, R. (2008). *Augmented reality and rigid body simulation for edutainment: the interesting mechanism - an AR puzzle to teach Newton physics*. Paper presented at the Advances in Computer Entertainment Technology.

Chasteen, S., & Pollock, S. (2009). *A Research-Based Approach to Assessing Student Learning Issues in Upper-Division Electricity & Magnetism*, Ann Arbor (MI).

Dede, C. (2009). Immersive Interfaces for Engagement and Learning. *Science, 323* 66-69.

Dünser, A. (2005). *Trainierbarkeit der Raumvorstellung mit Augmented Reality [Trainability of spatial ability with augmented reality]* Unpublished Doctoral, Vienna, University of Vienna. Doctoral thesis.

Dünser, A. (2008). Supporting Low Ability Readers With Interactive Augmented Reality. *Annual Review of CyberTherapy and Telemedicine: Changing the Face of Healthcare. Interactive Media Insistute* (6), 41-48.

Dünser, A., Grasset, R., & Billinghurst, M. (2008). A survey of evaluation techniques used in augmented reality studies. *ACM SIGGRAPH ASIA 2008 …*.

Dünser, A., & Hornecker, E. (2007). *An observational study of children interacting with an augmented story book.* Paper presented at the Edutainment 2007, CUHK, Hong Kong.

Dünser, A., Kaufmann, H., Steinbügl, K., & Glück, J. (2006, 6.-7. July). *Virtual and Augmented Reality as Spatial Ability Training Tools.* Paper presented at the CHINZ 2006, University of Canterbury, Christchurch, New Zealand.

Grasset, R., Dünser, A., & Billinghurst, M. (2007). *Human-Centered Development of an AR Handheld Display*. Paper presented at the International Symposium on Mixed and Augmented Reality.

Grasset, R., Dünser, A., & Billinghurst, M. (2008). *Design of a Mixed-Reality Book: Is It Still a Real Book?* Paper presented at the ISMAR 2008, Cambridge, UK.

Hampshire, A., Seichter, H., Rapha\, \#235, Grasset, l., & Billinghurst, M. (2006). *Augmented reality authoring: generic context from programmer to designer*. Paper presented at the 18th Australia conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments.

Johnson, L., Smith, R., Willis, H., Levine, A., & Haywood, K. (2011). *The 2011 Horizon Report* Austin, Texas: The New Media Consortium.

Kato, H., & Billinghurst, M. (1999). *Marker tracking and hmd calibration for a video-based augmented reality conferencing system.* Paper presented at the IWAR99.

Kaufmann, H., & Dünser, A. (2007). *Summary of Usability Evaluations of an Augmented Reality Application for Geometry Education.* Paper presented at the HCI International 2007, Bejing, China.

Liarokapis, F., Petridis, P., Lister, P., & White, M. (2002). Multimedia Augmented Reality Interface for E-Learning (MARIE). *World Transactions on Engineering and Technology Education, 1*, 173--176.

Liu, T. Y. (2009). A context-aware ubiquitous learning environment for language listening and speaking. *Journal of Computer Assisted Learning, 25*(6), 515-527.

MacIntyre, B., Gandy, M., Dow, S., & Bolter, J. D. (2004). *DART: a toolkit for rapid design exploration of augmented reality experiences*. Paper presented at the Proceedings of the 17th annual ACM symposium on User interface software and technology.

Moreno, R., & Mayer, R. E. (2005). Role of guidance, reflection, and interactivity in an agent-based multimedia game. *Journal of Educational Psychology Review, 97*(1), 117-128.

Moreno, R., Mayer, R. E., Spires, H., & Lester, J. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instructional Science, 19*, 177-213.

Rosenblum, L. (2000). Virtual and Augmented Reality 2020. *IEEE Comput. Graph. Appl., 20*(1), 38-39.

Seichter, H., Looser, J., & Billinghurst, M. (2008). *ComposAR: An intuitive tool for authoring AR applications*. Paper presented at the Proceedings of the 7th IEEE/ACM International Symposium on Mixed and Augmented Reality.

Shelton, B. (2002). Augmented Reality and Education. *New Horizons for learning*. Retrieved from http://www.newhorizons.org/strategies/technology/shelton.htm

Shelton, B., & Hedley, N. (2004). Exploring a Cognitive Basis for Learning Spatial Relationships with Augmented Reality. *Technology, Instruction, Cognition and Learning, 1*(4), 323-357.

Tamim, R. M., Bernard, R. M., Borokhovski, E., Abrami, P. C., & Schmid, R. F. (2011). What Forty Years of Research Says About the Impact of Technology on Learning: A Second-Order Meta-Analysis and Validation Study. *Review of Educational Research*.

Tobias, S., & Duffy, T. M. (2009). *Constructivist instruction: Success or failure?* New York: Taylor & Francis.

Vilkoniene, M. (2009). Influence of Augmented Reality Technology upon Pupils' Knowledge about Human Digestive System: The Results of the Experiment. *US-China Education Review, 6*(1), 36-43.