Why should my students use AR?
Reviewing the educational impacts of augmented-reality.

Iulian Radu
Public Broadcasting Service (PBS) KIDS Interactive

ABSTRACT

Augmented reality is increasingly reaching young users such as elementary-school and high-school children, as their parents and teachers become aware of the technology and its potential for education. Although research has shown that AR systems have the potential to improve student learning, the educator community does not clearly understand the educational impact of AR, nor the factors which impact the educational effectiveness of AR. In this poster, we analyse 32 publications that have previously compared learning effects of AR vs non-AR applications. We identify a list of positive and negative impacts of AR on student learning, and identify potential underlying causes for these effects. Further, we present a heuristic questionnaire useful for judging the educational potential of AR experiences. Our vision is that educational initiatives will exploit these factors, in order to realize the full potential of AR to enrich learner's lives.

Keywords: Augmented Reality, Education, Children, Human Factors.

Index Terms: H.5.1 [MULTIMEDIA INFORMATION SYSTEMS]: Information Interfaces and Presentation - Artificial, augmented, and virtual realities; K.3.1 [COMPUTERS AND EDUCATION]: Computer Uses in Education; H.1 [MODELS AND PRINCIPLES]: User/Machine Systems - Human Factors

1 INTRODUCTION

A relatively high amount of research papers have investigated the potential impact of augmented reality to benefit student learning. These diverse research programs can provide useful information for educators and technology designers interested in enriching young students' minds through novel technologies. Currently, however, there is no comprehensive understanding of the educational impact of AR. Having an integrated analysis of the various research studies can provide a theoretical basis, as well as practical guidance, to current and future educational initiatives interested in leveraging the educational benefits of augmented reality.

This poster presents a step towards such an integration. We have conducted a literature review of academic publications that investigated how human learning differs between AR and non-AR experiences. From the analysis of these publications, we have identified positive and negative effects that AR has on learners. Furthermore, we have identified various technological and psychological factors that may account for the observed learning effects, and developed a questionnaire for scoring these factors in existing AR experiences. By integrating these research findings and highlighting the potential underlying factors, we are constructing a model of the factors that may maximize the use of AR for learning.

2 POSITIVE LEARNING EFFECTS

This section reports on the positive impact that AR has been shown to have on learners, as compared to non-AR initiatives.

Increased Content Understanding: A large proportion of the surveyed papers indicate that for certain topics, AR is more effective at teaching students than compared to other media such as books, videos, or PC desktop experiences.

- *Learning Spatial Structure and Function:* In 29% of the comparison studies, students are successfully taught about spatial domains - such as geometrical shapes, chemical structures, mechanical machinery, astronomy configurations, or spatial configuration of human organs. The studies indicate that students learn better when using AR than when using either printed media, or using desktop software (eg: [1]).
- *Learning Language Associations:* Other studies have looked at using AR for teaching symbolic associations, such as teaching the meaning of written words (eg: [2]). Children's memory, as well as reading and writing scores, improve more when learning through AR, as compared to learning with a textbook.
- *Learning Physical Tasks:* Many studies have showed that AR is more effective than using traditional media when performing or training a physical task. For example, through an AR experience, maintenance tasks are performed with higher accuracy, and students are better able to transfer their learning to operating physical machinery (eg: [3]).

Long-Term Memory Retention: Research indicates that content learned through AR experiences is memorized more strongly than through non-AR experiences. In a series of studies, Vincenzi and colleagues [4] showed that content learned through an AR experience is significantly more likely to be recalled one week later, than compared to content learned through paper or video media.

Increased Student Motivation: The users' high enthusiasm to engage with AR experiences is noted in multiple papers, where users report feeling higher satisfaction, having more fun, and being more willing to repeat the AR experience. Interestingly, user motivation remains significantly higher for the AR systems (vs the non-AR alternative) even when the AR experience is deemed more difficult to use than the non-AR alternative (eg: [5]).

Improved Collaboration: AR experiences have been shown to cause improvements in group collaboration, as indicated by several papers surveyed. For instance, in a mobile experience, student team cohesion was stronger when using an AR map than when using a purely digital map [6].

3 NEGATIVE LEARNING EFFECTS

This section reports the negative consequences observed when using AR vs. non-AR systems.

Attention Tunneling: In a portion papers, students reportedly experienced higher attentional demands from AR system. This resulted in the student ignoring important parts of the experience, or feeling unable to properly perform team tasks [7].

Usability Difficulties: Several studies find that users report AR systems as more difficult to use than the physical or desktop-based alternatives. As reported earlier, interestingly many of these studies also find that users like the AR systems more than the alternatives [5].

Ineffective Classroom Integration: In one paper, the authors show how AR can negatively impact the classroom experience. Kerawalla et al [8] indicate that in the non-AR experience, children were more engaged in exploration and role-play activities around the learning content, while in the AR experience, the teacher dominated the discussion and limited student engagement.

Learner Differences: Some studies reported that for some students, AR may not be an effective teaching strategy. In [2], the authors report that although low- and average-achiever students showed learning gains through the AR experience, high-achieving students did not. Another study indicates that students who were low-ability readers did not learn from parts of the AR experience.

4 Underlying Factors

What might be causing the beneficial learning effects? In reflecting on the literature review, we have identified several technological and psychological factors that may be influencing learning in AR.

Transformed Representations: In the AR medium, content is presented differently than in a non-AR medium: verbal descriptions become visual, static images become animated, 2D representations become 3D objects, and non-interactive content becomes interactive. These changes in representation can be educationally effective, as information becomes easier to process and appeals to different learning styles [9].

Aligned Representations: In AR, information is spatio-temporally aligned with physical items, thus reducing the need for learner to switch attention between different media or to mentally transform representations [3].

Natural Interactions and Reduced Cognitive Load: The ease-of-use of most AR systems reduces cognitive load, and can encourage student exploration and creativity [5]. This encourages students to actively engage with the content, and is likely a factor to improved learning. Further, embodied interfaces appear to be inherently motivational for users, leading to improved engagement.

Directed Attention: The AR overlay scaffolds user learning by directing the user's attention to relevant content. In physical assembly tasks, AR can effectively guide attention by highlighting important components. This mechanism effectively transfers to other spatial learning tasks, such as highlighting organs when learning human biology [10]

Presence and Embodiment: Several papers report that user's memory is better for content presented with AR than non-AR. The physical aspect of AR experiences likely causes enhanced memory encoding, as information is provided to learners through tactile and proprioceptive modalities [4]. Further, embodied cognition research indicates that physically enacting a learning experience has the potential to generate deep learning by activating kinesthetic schemas [11].

Dynamic 3D Simulation: AR learning applications are essentially interactive 3D simulations. Digital simulations are generally effective because they allow students to experience phenomena that are impossible or infeasible to visit otherwise, they are dynamic and interactive, and they scaffold and assess user learning. AR allows users to experience immersive collaborative simulations, leveraging the benefits of simulations in understanding 3D phenomena that would be difficult to comprehend through other media.

5 Heuristic Questionnaire

By accounting for the factors identified above, we are constructing a heuristic questionnaire to identify applications that maximize learning potential of the AR medium. Currently, the questionnaire is composed of the following questions:

1. Does the application transform the problem representation such that difficult concepts are easier to understand?
2. Does the application present spatially- and temporally-relevant information, reducing extraneous learner tasks?
3. Does the application direct learner attention to important aspects of the educational content?
4. Does the application enable learners to physically enact, or to feel physically immersed in the educational concepts?
5. Does the application permit students to interact with spatially-challenging phenomena?

6 Conclusion and Future Work

Through our literature review of 32 comparative AR publications, we have identified several positive and negative effects of AR on learning, as well as some potential factors underlying these effects. We will further develop the questionnaire, and validate its usefulness in helping to identify educational AR experiences. Future work should investigate how each factor influences the AR learning experience, and apply these constructs to designing effective educational AR experiences.

7 Acknowledgements

We would like to thank Jennifer M. Rodriguez of PBS KIDS for her thoughtful comments. The contents of this paper were developed under a grant from the U.S. Department of Education.[1]

References

1. Hedley, N.R. *Empirical Evidence for Advanced Geographic Visualization Interface Use*. in *International Cartographic Congress*. 2003. Durban, South Africa.
2. Freitas, R. and P. Campos. *SMART: a SysteM of Augmented Reality for Teaching 2nd grade students*. in *Proceedings of the 22nd British HCI Group Annual Conference on People and Computers: Culture, Creativity, Interaction - Volume 2*. 2008. Swinton, UK, British Computer Society.
3. Tang, A., et al., *Comparative effectiveness of augmented reality in object assembly*. Proceedings of the conference on Human factors in computing systems - CHI '03, 2003: p. 73.
4. Vincenzi, D.A., et al. *The Effectiveness of Cognitive Elaboration Using Augmented Reality as a Training and Learning Paradigm*. in *Annual Meeting of the Human Factors and Ergonomics Society*. 2003. Denver, CO, USA.
5. Kaufmann, H. and A. Dünser, *Summary of Usability Evaluations of an Educational Augmented Reality Application*. 2007: p. 660-669.
6. Morrison, A., et al. *Like bees around the hive: a comparative study of a mobile augmented reality map*. 2009. ACM.
7. Chen, Y.-C. *Peer Learning in an AR-based Learning Environment*. in *International Conference on Computers in Education*. 2008. Taipei, Taiwan.
8. Kerawalla, L., et al., *"Making it real": exploring the potential of augmented reality for teaching primary school science*. Virtual Reality, 2006. **10**: p. 163-174.
9. Mayer, R.E. and R. Moreno, *Nine ways to reduce cognitive load in multimedia learning*. Educational Psychologist, 2003. **38**(1): p. 43-52.
10. Nischelwitzer, A., et al., *Some Aspects of the Development of Low-Cost Augmented Reality Learning Environments as Examples for Future Interfaces in Technology Enhanced Learning*. Access, 2007: p. 728-737.
11. Abrahamson, D. and D. Trninic, *Toward an Embodied-Interaction Design Framework for Mathematical Concepts*. Design, 2011: p. 1-10.

[1] However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.