International Conference NEW PERSPECTIVES in SCIENCE EDUCATION

Designing Augmented Reality Experiences for Science Education

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Abstract

In science education, there are often highly three-dimensional concepts, processes, and objects which are difficult to understand in a two-dimensional context, yet, this is how we usually attempt to teach them. For example, when teaching chemistry we may attempt to describe an atom by drawing it on a whiteboard and describing it. Although this method can be beneficial, it leaves much up to the imagination and can often leave many students confused. However, augmented reality (AR) can be leveraged to help students not only visualize three-dimensional objects and ideas but interact with them in a meaningful way. It provides many affordances, such as recreating existing aspects of the physical world in a controlled environment or allowing visibility of things normally invisible to the naked eye. Using sound design principles and relevant earth science education content, we created an AR experience using the tether-free Magic Leap AR headset to enhance a 6-ft globe exhibit in a university library. It teaches about the Earth's magnetic field and how it protects the Earth from harmful solar particles. In designing and testing the experience, we have learned many valuable lessons about AR in science education and important considerations when designing and developing a virtual learning experience that we hope to share with the world.

Keywords: *Augmented Reality, Instructional Design, Earth Science.*

1. Background

The graduating class of 1966 left Brigham Young University (BYU) with a rare and memorable gift. Perhaps referring to the campus motto, "the world is our campus," this group of departing students gifted the University a 6-foot (1.8-meter) diameter geophysical relief globe.

In 2018, the Library began looking at ways of refreshing this exhibit, with a desire to increase the educational experience provided by this rare asset. Two engineering students proposed using augmented reality (AR) to add content to the globe. This emerging technology offers a means to provide the exhibit with nearly unlimited educational content and creates a lab for active learning. For example, students and instructors in geology, political science, anthropology, geographic information systems, etc. could use this platform to create and display data or other information in an engaging manner that connects events with their geographical context.

The following sections discuss lessons learned as we have progressed through the design phase of an AR application for this globe exhibit. We expect that our findings may provide value to those considering use of AR technology in their teaching efforts by illuminating aspects of the design process and by providing a basis for informed decision-making.

2. Literature Review

A study was recently published that provides profound insight into the affordances generated by AR technology [1]. These affordances include: diminishing negative aspects of the physical world, enhancing positive aspects of the physical world, recreating existing aspects of the physical world, creating aspects that do not exist in the physical world, and overcoming space-time linearity.

Researchers in educational fields have previously applied AR to help students learn abstract concepts in the Earth Sciences. Some report findings that using AR to learn difficult concepts decreases the cognitive load of university students and aids learning and retention [2]. Others utilize AR to create new opportunities for learning by facilitating student experimentation relating to what happens when the Moon is too close or too far away from the Earth [3].

3. Method

3.1 Project Definition

***Design goals & objectives*.** The application design, development, and implementation is meant to: 1) assist students in comprehending highly abstract concepts relating to the Earth; and 2) provide an example to students and teachers at BYU of a meaningful educational experience leveraging AR technology. To achieve these goals, the experience should incorporate active learning to increase engagement, and the quality of the augmentations should be realistic and immersive enough to increase comprehension, not distract from the learning experience, and truly represent the technology.

Target audience. To better understand our users, personas were developed for three types of individuals in our target audience [4]. The “curious freshman” persona captures the demographic of younger students that just want to experience AR in some form out of curiosity. The “struggling with physics” persona represents students who are struggling with understanding a certain concept and are interested in the AR platform as a study help. Finally, the “interested professor” persona represents the faculty and staff that have heard about AR and are looking for an example of its use in education.

These personas were informed by our literature review, some initial testing feedback, and frequent interaction with our user population as our classmates and colleagues. For example, one study found that 48% of BYU students reported being "not familiar at all" with AR technology and only 2% reported being “extremely familiar” with the technology [1]. We expect even lower rates of familiarity with AR being reported by faculty and staff.

3.2 Selection of appropriate content

The novelty of the technology is not a sufficient reason for employing it. However, in the context of the globe exhibit, compelling value is seen in AR’s ability to take abstract, difficult-to-visualize concepts and make them concrete and understandable. One such abstract concept is the Earth’s magnetosphere – the invisible yet powerful magnetic field that protects the Earth’s atmosphere. Since many have little concept of its presence or importance, we decided that this would be a good test of AR’s educational promise.

In designing this AR experience, learning outcomes were chosen that could exploit specific affordances of the technology. These include: 1) knowing that the Earth’s magnetic field is generated by its iron core, 2) explaining how the Earth is protected from solar wind, and 3) understanding that the northern lights are visible evidence of the magnetosphere.

Examples of how we leveraged these affordances to meet learning objectives include:

- Most representations in instructional materials utilize field lines to depict the Earth’s invisible magnetic field because of their simplicity and the 2-dimensional media typically used to depict the field. With AR, we are able to depict the true 3-dimensional nature of the field, utilizing AR’s affordance to *enhance the physical world*.
- AR can not only show a representation of the core of the Earth but can also facilitate *adding additional information* that does not exist in the physical world, such as the centreline axis of the Earth to assist in comprehension.
- AR allows visualizing an alternate reality that would be, were the magnetosphere absent. This exploits AR’s ability to *ignore space-time linearity*. Furthermore, spatial distances are not constrained to be to scale, and so the observer can play the role of another body in outer space interacting with the magnetosphere without being concerned with scale.
- Though it is possible to see visible evidence of the magnetosphere, an observer would need to travel far north to see this. The authors used AR to help users experience Aurora Borealis regardless of their location, capitalizing on AR’s ability to *recreate aspects of the physical world* in a location convenient to the user.

3.3 Structuring the Content

We used a cognitive task analysis (Fig. 1) when organizing the content for this learning experience [5]. This meant researching how experts think about the content and organizing it in the manner that they would. Task analyses seem especially appropriate for AR experiences as they provide additional direction and flow to the experience.

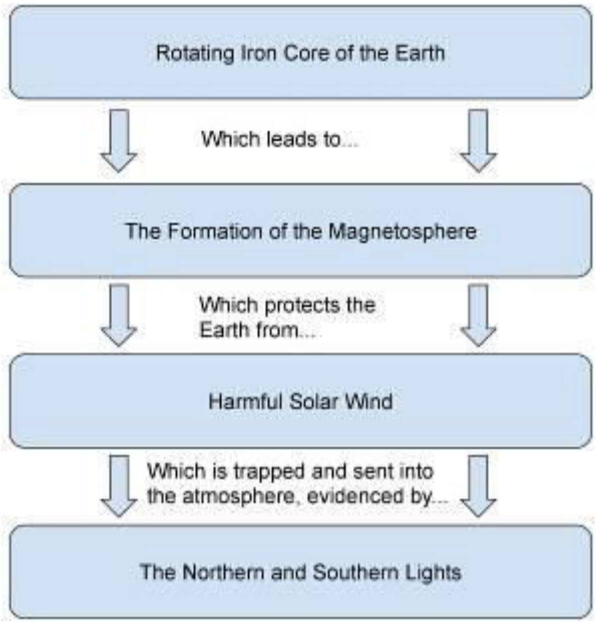

Fig. 1: Cognitive Task Analysis

In seeking to implement the principles of embodied cognition in our design, we found that it is valuable to involve the most interaction from the learner on the main learning objective [6]. In our AR app, this meant focusing the learner's interaction on the protection the magnetosphere provides by making an activity where the learner can use a controller to fire solar particles at the Earth and observe as its magnetic field deflects them (Figs 2, 3).

4. Results and Discussion

In designing our AR experience, we found rapid prototyping to be a useful method of instructional design. Per Nixon and Lee, this does not eliminate the need for sound learning theories on which instruction is based but, rather, it guides the designers as they create and revise a learning solution [7]. This was very helpful as it allowed weaknesses to be identified early in the design process.

Fig. 2: Controller becomes Sun in interactive activity

Fig. 3: User firing solar particles at magnetosphere

We asked some students to test a medium-fidelity version of our prototype and provide feedback. They suggested that we be clearer about the controls, create a more engaging introduction, and that we include more interactivity. Their feedback reinforced that interactivity usually increases engagement and should be implemented as often as feasible, especially on the parts of the lesson that are at the core of the learning objective. User comments also underscored that the communication of interactive controls should be clear and intuitive so that they do not detract from the learning objectives. Finally, we observed that what students see in the first few seconds influences their attitude toward the experience in large measure. By prototyping and testing often, designers and teachers can avoid ineffective or impractical designs for educational AR experiences.
One challenge noted in developing the prototype was the lack of documentation on and functionality of the head-mounted display AR software. All such devices on the market are immature consumer devices, so many 3D assets either do not show in the headset or require alterations in the code to get them to appear. Also, only one user can use the headset at a time, so class interaction is difficult unless more headsets are purchased. However, at $2300 USD each, multiple headsets are far from affordable for many.

5. Conclusion

In summary, AR development can be time-consuming and require a high amount of effort and planning, but AR provides affordances not offered by other media. In designing such experiences, great care should be taken in considering the audience, constraints, content, instructional design, and practical implementation. The content, especially, should be analyzed to determine whether an AR experience will provide perception, insight, and engagement unattainable through other methods. By employing these design practices, an engaging experience can result that fortifies understanding and forms mental connections not easily forgotten.

6. Future Work

An assessment phase will follow this design phase where feedback from those experiencing the magnetosphere exhibit will be sought. A survey will be administered to willing participants to gather quantitative and qualitative data regarding the experience – its instructional value, user-friendliness, and their assessment of the value of AR in education. Based on feedback, improvements to the initial application will be made, and future development efforts can be informed.

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