Collaborative Augmented Reality in Undergraduate Science Laboratories

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Students often have fundamental misunderstandings of how the physical world works (see Figure 1). They lack the cognitive framework to understand relatively simple physical systems. This problem is particularly acute in understanding sizes, scales, and geometric alignments. The root of this problem lies in how we visualize and teach these systems within the science classroom. Preconceptions created through bad educational experiences are difficult to dislodge without directly challenging these assumptions.

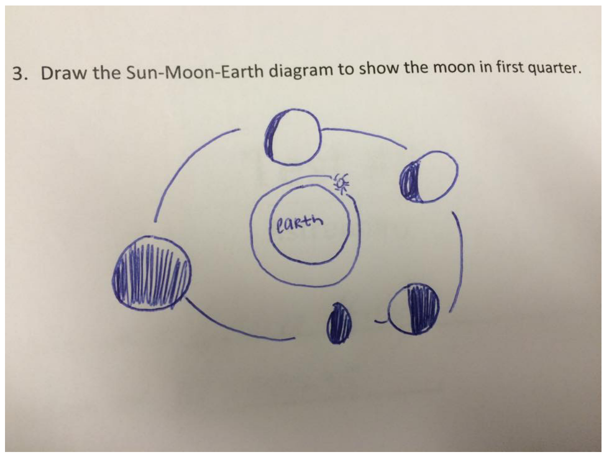

Figure 1: An undergraduate student in an introductory astronomy lab attempt to illustrate the first quarter phase of the moon. Note the Sun is found in a close orbit around the Earth.

Studies of early AR in learning environments have shown that it is well suited for visualizing sizes and scales. This type of information is critical in overlaying contextual information in experiments, particularly in inquiry-based learning. However, there are few studies of the pedagogical best practices to use AR effectively [1]–[3]. One of the main difficulties of previous studies was the maturity of the technologies. It was challenging to study how groups of students interacted in an augmented classroom. Although there have been some studies of collaboration using AR [3]–[10], there still are relatively few AR hardware platforms available to study these group interactions. At the same time, most of the AR apps that focused on education were designed to be used by individual students and do not take advantage of the best teaching practices in science classrooms. *The critical difference between our project's goals and previous attempts at AR in classrooms is our focus on immersive AR in a group learning environment.*

We know that spatial visualizations are essential in STEM education. Students often struggle with visualizing concepts based on text descriptions [11]. Individual differences in visuospatial ability may interfere with the AR instructional approach to affect learning [12]. These differences in visuospatial ability may be particularly significant in academic subjects such as chemistry and astronomy. Understanding a molecule's three-dimensional structure determines its function. Understanding the alignments that produce eclipses or moon phases can be daunting without a solid geometric foundation of the sizes and scales involved. Students have misconceptions because they misunderstand the underlying spatial concepts. Visualizations combined with active learning experiences can help students develop an "intuitive understanding" of how these complex systems work.

It is critical to note that visualizations by themselves do not create cognitive change. Watching a video demonstrating moon phases or running a computer simulation of an eclipse can convey the information needed to understand these systems, yet they do not necessarily lead to learning. Learning is not magical, and it is not automatic. It is not a passive activity. People need to interact, discuss, and even argue about what they see to change the visual information into knowledge and understanding. Actively engaging physically with the content is an established principle of active learning [13]. Group discussions about the content (such as those promoted by the POGIL method) have their basis in social cognitive theory [14]. Social interactions in small groups settings can promote a willingness to learn and a higher quality of learning.

Beyond the student experience, the interaction between a teacher and the AR environment is critical within this context. A teacher needs to be able to discuss the concepts with their students, but also to author and edit AR content for their class. Teachers need to be able to track and facilitate learning. They need to be able to create experiences where learning will happen. Teachers cannot just be passive consumers of pre-released software. Instead, they must be active participants in shaping the learning environment.

However, it is possible and perhaps even likely that AR technology's introduction into small group laboratory settings will promote unpredictable behaviors and reactions. Our group is working on creating a prototype environment to explore these issues (see Figure 2).

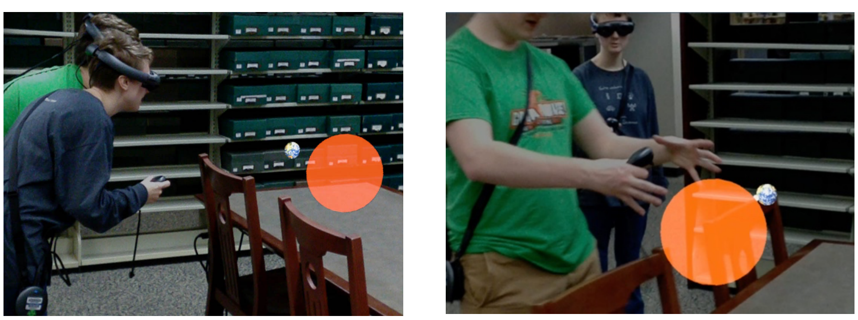

Figure 2 – a view of a prototype shared environment for students in the sciences to explore complex visualizations. We created these visualizations using the Magic Leap One platform in a shared environment.

An instructor will author educational modules that include interactive objects, exercises, and student instructions. Since this project's focus is on evaluating the technology's impact rather than deploying it, this initial interface will be relatively simple. The instructor will help manage the student data that we track during the experiments. The initial student database will be simplified to protect student data.

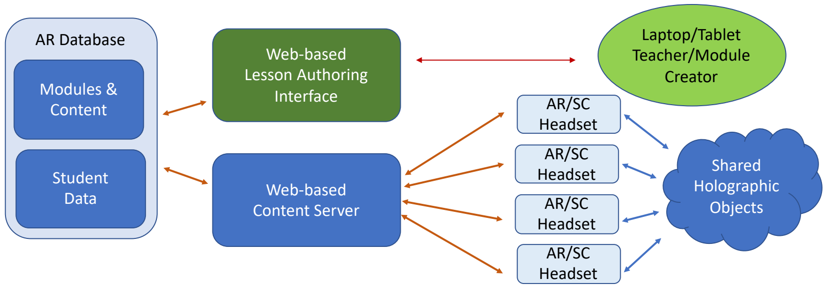

Figure 3. Overview of connection between content database, the headsets, and shared AR environment.

The AR headsets will connect to the web-based content server. The server will send JSON data to the units that define the virtual objects and the interactions needed to complete the task. The devices will instantiate these shared virtual objects. The peer-to-peer connectivity between the AR devices that will synchronize the scene across participating students. Students and the teacher will interact with shared objects through hand tracking and the controller. Other interactions will be scripted through tablets or smartphones if additional textual information is needed. We have already prototyped the content server, content module database, and the AR headsets' software.

Future software development will revolve around a few areas: initial content authoring and loading, dynamic modifications to current content, and student interaction tracking (for eventual grading and evaluation). The key proposed software development activities are:

- *Improving and formalizing the prototype API used in the initial loading of learning modules into the web-based content server*.
- *Devising and enhancing a mechanism for dynamically altering the content and behavior of modules*.
- *Developing functionality to capture and log student interactions and results*.

The above components will provide a layer between the users (faculty and students) and the spatial computing system that shields users from the inevitable OS and SDK changes. Formalizing this interface will allow users to upload, remove, or change instructional content and download student interactions and performance data.

The fundamental issue in this research is not technological. The primary questions are whether social interactions in an augmented reality environment facilitate discussion, learning, and understanding. How do students interact with each other? How does a teacher create the content needed to spark these discussions? Can we use shared immersive experiences and social interactions to build create knowledge and understanding in a complex world?

Funding for this research was provided under the NSF 17-598 Cyberlearning for Work at the Human-Technology Frontier solicitation under award number 2017011.

Project Team

John Wallin, an astronomer computational scientist responsible managing the software team and designing the content for astronomy applications.

Andrienne Friedli, PI of the previous Chemistry hyperwall pilot project. Her focus is on transforming learning content from CHEM-1 into to AR/SC examples.

Sal Barbosa is an early career faculty member in Computer Science with a background in Virtual Reality, AI, and software development.

Neal McClain is the Director of Technology at MTSU's Walker Library and brings their resources including workstations, software, MLV1 headsets, and professional staff to maintain them.

Rafet Al-Tobasei is an early career faculty member in Computer Science with a background in Bioinformatics.

Michael Hein is the Director of the Center of Organizational Performance and Human Resources Effectiveness (CORE) and has extensive experience in performance appraisal and organizational performance.

Amy Phelps is a chemical education researcher and master teacher who has worked with stereo-3D visualizations in CHEM-1.

Student programmers

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Isaac Shirk
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