Determining Design Requirements for AR Physics Education Applications

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Figure 1: AR image capture of the headset presenting a ramp with a bouncing ball which interacts with the spatial mesh captured by the Hololens.

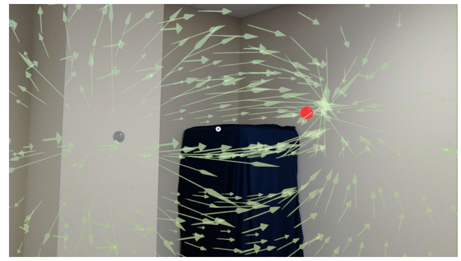

Figure 2: AR image capture of the headset presenting a point charge electrical field as an illustration of Coulomb's Law.

Abstract

While we are in the midst of a renaissance of interest in augmented reality (AR), there remain a small number of application domains which have seen significant development. Education is a domain that often drives innovation with emerging technologies. One particular subject which benefits from additional visualization capabilities is physics. In this paper, we present the results of a series of interviews with secondary school teachers about their experience with AR and the features which would be most beneficial to them from a pedagogical perspective. To gather meaningful information, a prototype application was developed and presented to the teachers. Based on the feedback collected from the teachers, we present a set of design recommendations for AR physics education tools, as well as other useful collects comments.

Keywords: Augmented Reality, Physics Education, Qualitative Interview

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

1 Introduction

As it stands today, there is no apparent "killer app" for augmented reality (AR), head-worn or otherwise. From a consumer perspective, there is little incentive to invest in anything beyond smartphone/tablet-based AR applications. In the industrial space, the primary application of head-worn AR is training or task guidance. Education is one area that often drives exploration when new technologies are developed [4, 5]. Novelty lessons are used to drive up interest in subjects which students avoid.

A non-trivial number of students often do poorly in physics and other introductory courses, which pushes them out of engineering and related STEM fields [3]. A contributing factor for this is that physics is the first science course which students encounter that requires the application of mathematical knowledge to the real world. Physics courses often emphasize laboratory work as an avenue for reinforcing lecture topics. For concepts like projectile motion, energy, and friction, an in-person lab with physical objects is the perfect medium for illustration. However, concepts like electricity, magnetism, and light waves are not as easily seen or understood from standard laboratory studies. Educators often find creative ways to assist students in understanding these concepts, often using web applications or physical props for assistance. With the advent of consumer grade, head-worn AR solutions like Microsoft's Hololens or the Magic Leap One, we can determine if providing alternative methods of presenting lessons to students is beneficial.

Still, a platform is only as useful as the applications which are developed for it. Prospective developers for modern AR platforms would likely benefit from information about their target use cases. In this paper, we present a qualitative analysis of a prototype AR application for the Microsoft Hololens with a focus on physical science education. We briefly detail the application and some of the more prominent features. We then present a requirements gathering interview of a handful of teachers. Based on a thematic analysis, we present a set of design requirements which would need to be satisfied to meet the laboratory needs of a physics course and helpful comments which may assist developers in making design choices.

A previous survey by Billinghurst et al. gives a thorough survey of the AR field overall [1], including education applications. Perkins et al. [5] developed PhET Interactive Simulations[1] (PhET), a well researched and widely used, traditional web-based application for physics education, with other sciences also being featured. A number of demos for different concepts are featured on the page as illustrated figures which can be used as lab assignments, interactive demonstrations, or exploratory studies. A straightforward way to ensure adoption of a new application is to ensure it meets the needs of existing applications and enhances them in some way. Our prototype enables physics concept visualization in a similar manner, but with considerations for AR content and information presentation.

2 Methods

We developed a prototype application, HoloPhysics, for the Microsoft Hololens to illustrate a handful of physics topics which could

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[1]https://phet.colorado.edu/

be used as proof of concept for demonstration purposes. HoloPhysics consists of a number of self-contained demonstrations for illustrating a specific physics concept using virtual objects in the physical space. These included electrical fields (See Figure 2), elastic collisions (See Figure 1), and parallel circuits.

We conducted semi-structured interviews of six secondary and post-secondary science teachers to determine what utility they can see in our prototype. The teachers ages ranged from 26 to 59 ($M = 40.5, SD = 13.8$) and experience ranged from 1 to 31 years ($M = 13.0, SD = 11.6$). Half were female. Only two had any experience using AR or VR in their classrooms. All six had used PheT in their courses. The interviews were used to determine what kinds of features would be most important to encourage adoption of AR as an alternative or supplement for physics laboratories.

Teachers were asked about their experience with AR/VR, existing educational software for physics labs, and what type of labs they conducted in their courses and in what context (reinforcement vs. exploration). Interviewees were then presented with a demonstration of HoloPhysics, and were then allowed to explore the demonstrations firsthand. The interviewee was asked another set of questions related to HoloPhysics and what features they consider mandatory in any application they would use in their course.

Pen, paper, and a voice recorder were used for data collection. A total of 3.5 hours worth of recordings and notes were collected and transcribed for thematic analysis. We organized these themes into two overlapping sets, those which were preliminaries connected to the individuals' experiences or teaching style, and those themes which were directly related to the demo presented and recommendations emerging from them. The resultant themes included *Novelty*, *Reinforcement*, *Exploration*, *Variable Presentation*, and *Collaboration*.

3 Results and Discussion

While there is an existing body of work in tablet/smartphone-based AR education applications [2], the content that can be presented using head-worn AR differs to some degree. Based on the themes we discovered and comments compiled during our evaluation, we developed a collection of recommendations.

Augment the Visible. General consensus in the interviews was that the simple ball visualization was not particularly useful for classes as implemented in HoloPhysics. Teachers would prefer to see force diagrams and vectors added to the scene to assist in understanding why objects moved the way they did. This visualization extends across multiple physics subjects like kinematics, electricity, and magnetic force. Augmenting the presentation of information in this way speaks to the *novelty* and *variable presentation* themes which were present in the analysis.

Visualize the Invisible. Concepts such as electricity and magnetism which are not easy for many students to grasp at first exposure are better suited to AR than traditional labs. Normally, students are limited to computer based simulations or figures from textbooks for illustrations of these concepts. By presenting them in AR in real space, it is possible to reinforce the concepts by providing spatial integration in some way. An example of this is presenting magnetic fields around a physical bar magnet so students can understand the way the orientation of the magnet influences the fields around it. Similarly, a head worn AR display can be used to provide instructions to the student by using the built in cameras to detect mistakes and provide guidance to correct them. This recommendation is based on the *novelty*, *variable presentation*, and *exploration* themes.

Present Both Concepts and Calculations. Teachers frequently pointed out that students learn at different levels and benefit from different presentations of information. Multiple teachers pointed out that most students benefit directly from seeing concepts in an informal way prior to delving into the math for *exploration* or *reinforcement*. In this way, we would recommend supporting the presentation of both concepts and calculations to students within the application. Some students may prefer to directly manipulate the equations and watch changes, while others like to drag and drop items. PhET implements this idea in a large number of the simulations it features [5]. The option to disable or enable components echoes the theme of *variable presentation*.

Enable Collaboration and Demonstration. One teacher made a strong case for developing tools that would enable lecturers to present augmented content to students in the form of first person demos. Others stated that a handful of students at a time should be working with a single device or single space as a shared experience. Augmented reality enables collaboration via remote video playback of the live feed from the headset or by presenting a shared experience to multiple users in distinct spaces. Applications which are developed with classroom use in mind should consider which specific use cases they would like to support, be it a lecturer's role or one where multiple students are interacting with a scenario simultaneously, as they often do in labs. There are often far fewer lab stations than there are students, so students must take turns using lab equipment. It would be beneficial to integrate support for experience sharing among students, that way each student is able to observe an experiment or concept at their own pace. An example of this would be allowing students to rerun a rocket launch with the same parameters and random seed to ensure consistent data.

4 Conclusion and Future Work

In this paper, we presented the results of a series of interviews wherein comments were collected based on a series of questions detailing experiences and opinions from a prototype Hololens application for physics students. We uncovered a set of five relevant recurring themes: *Novelty*, *Reinforcement*, *Exploration*, *Variable Presentation*, and *Collaboration*. The responses gathered point towards a healthy set of features which should be supported to encourage adoption.

In the future, we would like to incorporate more of the recommended concepts and the presentation of the backing equations for the labs in an updated prototype and evaluate it in secondary and post-secondary classrooms and collect student feedback. Additionally, teachers also could benefit from improved authoring tools for content. Though most teachers would consider themselves non-technical, they do have ideas for novel labs and experiment ideas that were created outside of those recommended in teacher manuals. We would also like to develop tools to allow teachers to construct their own AR experiences which they can tailor to their specific course curriculum. This extensibility would improve long term utility.

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