# PhyAR: Determining the Utility of Augmented Reality for Physics Education in the Classroom

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## Abstract

Physics is frequently cited as a difficult roadblock and hindrance to retention in STEM majors. In this paper, we present the results of a study exploring the potential utility and use cases of augmented reality in secondary and post secondary physics courses. To gather meaningful information, we developed PhyAR, prototype physics education application in augmented reality. We collected feedback and opinions from a qualitative study of university students with STEM backgrounds. Our findings point towards a clear desire to see the use of more interactive 3D AR content in physics courses.

**Keywords:** Augmented Reality, Physics Education, Qualitative Study

**Index Terms:** Human-centered computing—Human computer interaction (HCI)—Empirical studies in HCI; Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality;

## 1 Introduction

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 augmented reality (AR) solutions, we can determine if providing alternative methods of presenting lessons to students is beneficial. These newer devices feature inside-out tracking and are completely wireless. These two features combine to allow easier setup in new environments and a lower barrier to entry than older technologies. This enables easier distribution of AR content to audiences which may have previously seen the technologies as niche or cumbersome.

In this paper, we present a qualitative analysis of a prototype augmented reality application for the Microsoft Hololens with a focus on physics education. We first detail the application itself and some of the more prominent features. Based on an existing study of educators and a focus group of students, we developed a revised prototype which we then evaluated in a laboratory study with university students. Finally, we report the feedback of this qualitative study and discuss implications for classroom adoption.

## 2 Related Work

Existing work in the AR education space includes MagicBook, which is seminal work in AR education because it enabled people to see 3D content projected over their 2D books [1]. Dünser et al. created a spiritual successor to MagicBook which used ARToolKit and OpenSceneGraph [3]. The framework enabled students to create virtual books that overlayed on printed text books and allowed for gestural interaction. Results showed that AR was potentially beneficial for teaching electro-magnetism concepts. Bujak et al. discuss the importance of having some physical affordances in the mixed reality environment to improve symbolic understanding [2]. We developed a scenario with this in mind, making sure to align virtual objects with a similar anchor in the real world.

Perkins et al. developed PhET Interactive Simulations (PhET), a widely used web-based application for physics education, with other sciences also being featured [4]. 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 draws inspiration from PhET and enables physics concept visualization in a similar manner, but with improvements for 3D content and information presentation.

## 3 Methods

Our prototype application, PhyAR, was developed using Unity3D[1] and the Mixed Reality Toolkit[2] for use with the Microsoft Hololens. PhyAR consists of a number of self-contained demonstrations for illustrating a specific concept using virtual objects in the physical space. The application design was influenced by a previous set of educator interviews [5]. Each of the demonstrations was based on a concept from a secondary school physics class, as presented in Figure 1. The demonstrations had varying levels of environmental interaction. The concepts illustrated included the following:

- *Coulomb's Law* - A 3D grid of vectors is presented to the user, along with a number of point charges. The user can add or remove the point charges, as well as translate them in space. The grid of vectors update in real time, presenting the charge at the point in space according to Coulomb's Law.
- *Elastic Collision* - A ball is presented to the user along with a flat panel with a description of the "coefficient of restitution." Some physical properties can be altered by the user by manipulating sliders on a 2D canvas, including the coefficient of restitution, initial height, and friction of the surface of the ball. The ball interacts with the spatial mesh generated by the Hololens.
- *Parallel Circuits* - Users are presented with a parallel circuit visualization of the lights in the room they are in. A virtual light switch can be toggled on or off and the corresponding light and circuit will be switched on or off, respectively. The positions of the virtual lights and light switches were manually calibrated and anchored to align with real objects.
- *Volume* - The user is presented with a panel describing the concept of geometric volume and the equation for the volume of a cylinder. A cylinder is presented in the scene which can be moved and

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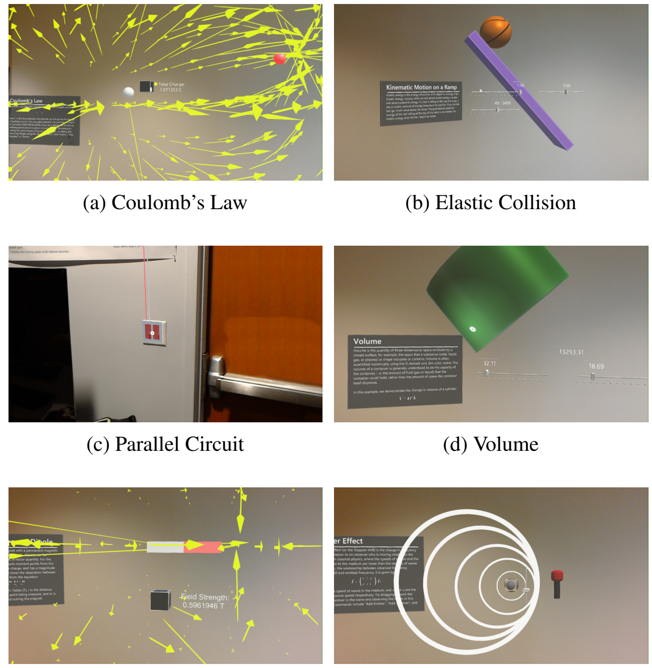
[1]https://unity3d.com/
[2]https://github.com/Microsoft/MixedRealityToolkit-Unity

rotated by the user. Two sliders are also presented to the user, one for height and one for radius.

- *Magnetic Field* - A 3D grid of vectors is presented, along with a fixed bar magnet and a magnetometer. The user can move, rotate and scale the magnet and observe the change in magnetic force at each point. The vector field visualization updates as the magnet is moved according to the equation for magnetic force at a point outside of a fixed dipole magnet.
- *Doppler Effect* - The user is presented with a text panel describing the mathematical basis for the Doppler effect and an explanation of how to use the application. In the scene are receivers and emitters, with the emissions being visible as sphere outlines from the center of the emitter. When an emission reaches one of the receivers, a tap sound is played. As the objects move closer and further apart, the perceived frequency of the taps changes.

An exploratory qualitative study was conducted to gather feedback from students on the prototype and to determine where they would like to see it used in their courses. Fifteen participants (13 male, 2 female) were recruited with ages ranged from 21 to 31. Ten of the fifteen had VR experience, seven had AR experience. All participants were required to take two physics courses for their degree program.

Participants were presented with each of the six concepts. They were free to explore each concept until they were satisfied that they had experienced all of the features within each scene. They were then asked to complete a post-study questionnaire comprised of 5-point Likert scale questions and free response questions about possible use cases and preferences.




(a) Coulomb's Law (b) Elastic Collision

(c) Parallel Circuit (d) Volume

(e) Magnetic Field (f) Doppler Effect

Figure 1: AR image captures presenting different conceptual visualizations from the PhyAR application on a Microsoft Hololens.

## 4 Results and Discussion

Overall, participants found the system to be easy to understand ($M = 4.60, SD = .51$), exciting ($M = 4.60, SD = .51$), motivating ($M = 4.27, SD = .80$), and interesting ($M = 4.87, SD = .35$). These results were expected as there is typically positive feedback from participants when exposed to a new application. To a lesser extent, users found that they could learn more than a lab session($M = 3.8, SD = .87$), formal lecture ($M = 3.53, SD = 0.91$), or textbook ($M = 3.86, SD = .74$) using PhyAR or a similar, fully-featured application. Participants wanted to continue using the AR application after the study ($M = 4.27, SD = 1.10$) and felt that they could learn more from a more complete application ($M = 4.46, SD = .64$). Students also responded positively to the ideas of augmented lectures using a remote display to see an augmented lecture ($M = 4.47, SD = .83$) and sharing a space with other students in an augmented physics lab ($M = 4.27, SD = 1.03$).

Sixty percent of participants reported that they found the dynamic visualizations to be one feature they liked. Similarly, 60 percent of participants liked that the application was interactive in some way. Most of the dislikes reported were the result of device specific issues relating to limited field of view causing objects to not be visible in the room. Three of the 15 students had specific problems with the hardware being uncomfortable. Nearly half of participants had problems with built-in controls of the Hololens, specifically with the pinch gesture needed to select the objects in the scene and two handed pinching to manipulate objects. The proctors ensured that the participants were able to appropriately execute the gestures. It can be assumed that future devices will enable better native interaction and be designed with extended use in mind so these would no longer be issues. Students saw possible use for exploratory study on their own time, in collaborative laboratories with shared spaces, and with instructors presenting augmented lectures.

## 5 Conclusions and Future Work

The version of PhyAR presented to participants did not include any physical world interaction outside of spatial mesh collisions in the elastic collision demo. This is a shortcoming of the study as it primarily leverages the AR display but not the environment around the user outside of the basic geometry of the room. In the next version of the study, we are integrating physical objects into the AR experience to better use the AR display capabilities.

We presented the results of an exploratory study of an AR physics education application for head worn devices. Participants reported generally positive experiences with the application and neutral experiences with the hardware. Feedback collected from students will be used to inform the design of future iterations of PhyAR, with particular emphasis on adding interaction with real world objects.

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