Board 415: Understanding Magnetism Concepts Through Augmented Reality: A Qualitative Analysis

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Understanding Magnetism Concepts Through Augmented Reality: A Qualitative Analysis

Abstract
Many physics and engineering students struggle with conceptual understanding of electricity and magnetism concepts that involve visualizing abstract 3D models. An augmented reality (AR) app called MARVLS: Physics II E/&M developed for a smartphone or tablet, allows students to interact with many different conceptual models in a second semester introductory physics course. In this study, we examine how students develop conceptual understanding as they interact with an augmented reality model representing the magnetic field surrounding a long current bearing wire in the MARVLS App. A grounded theory framework is used to analyze semi-structured interviews with students as they use the App through guided interactions with the AR models. This study examines how students incorporate manipulable AR visualizations into their conceptual understanding of magnetism concepts.

Introduction

There are many abstract concepts encountered in introductory physics courses that cannot be seen or touched. These concepts can be illustrated using diagrams and can be represented using symbols and mathematical equations. However, even after seeing the diagrams and learning how to manipulate the symbols and equations, it can still be difficult to truly understand these concepts without being able to hold them in our hands and view them. The Manipulable Augmented Reality Visualizations to Learn Spatially (MARVLS) smartphone apps use augmented reality (AR) and Merge© cubes to allow students to hold the diagrammatic representations of the abstract concepts, rotate and move them around in space, and investigate the connections between the 2D and 3D models and the mathematical formulas [1,2]. These interactions allow students to apply what they've learned in a more tangible way and can even open up new areas of learning for students who believe they already have a strong familiarity with the concept. The goal of this study is to use a simulated 3D projection that allows students to manipulate and view models from different vantage points until the visualization becomes familiar from all angles, and then assess the ways they engage and how this engagement elevates their overall understanding, as well as their interest and confidence in the concepts presented to them. This study is part of a larger study of how students use AR visualizations through a smartphone app to enhance their conceptual understanding of magnetism concepts. This study focuses on the magnetic field surrounding a long current carrying wire.

Purpose of the study

The purpose of this grounded theory study is to develop a central theory to guide the development of an AR model and activity to facilitate students' integrating 3D AR models, 2D representations, and the right-hand-rule into their conceptual understanding so they can accurately, succinctly, and clearly understand and describe the magnetic field of a wire. In this regard, the study aims to answer the research question: How do students develop conceptual understanding as they interact with the augmented reality model of the magnetic field of a current-carrying wire? The research question is answered in the context of the following conditions:

1. The conceptual understanding of students through guided exploration of the magnetic field of a current-carrying wire in the MARVLS App.
2. There are two groups of students including physics majors or minors and psychology students as participants in a research study of their choice.

The AR 3D model and lesson for the magnetic field of a current-carrying wire

As shown in Figure 1, the components of the 3D model include a translucent cylinder representing a wire, buttons to display positive current and negative current, a button to turn on the magnetic field, and a button to turn on a 2D representation. The positive current is represented by little blue spheres that drift upward through the wire, while the negative current is represented by little red spheres that drift downward. The MARVLS models also include a feature to highlight mathematical relationships. In the bottom right corner, the 2D picture acts as a button to highlight specific magnetic field arrows in the 3D model if you press and hold it.

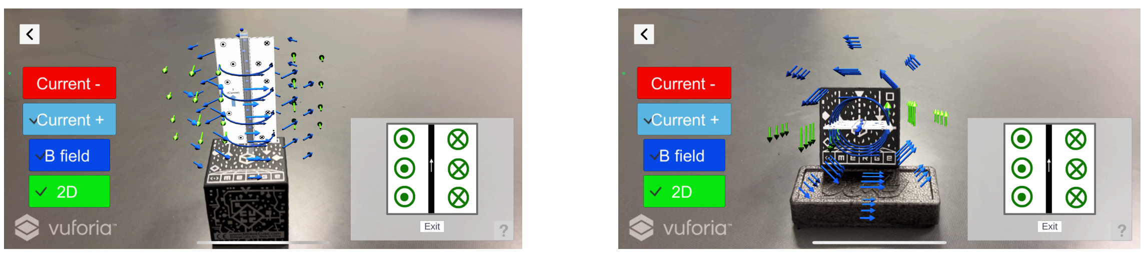

Figure 1. Magnetic field AR model (a) front view and (b) top view.

Choice of qualitative method

A grounded theory methodology was chosen to understand the different ways the students were using the MARVLS App and viewing the AR 3D model, their descriptions of what they were observing, and how those observations and actions within the App were informing their understanding of the physics concepts. The MARVLS App is a novel approach to support conceptual understanding of magnetism using augmented reality and studies in the literature are limited. The study involves in-depth student interviews detailing their learning process through think-alouds while they are working with the App and cube and retrospective questions after their interactions with the App. Because of these two reasons, a grounded theory methodology is well suited to analyze the interview transcripts [3].

The MARVLS Apps are a new augmented reality teaching resource. A grounded theory study of how students use the App and interact with the augmented reality model will guide research-based modifications to the AR 3D models and user interactivity to optimize students' conceptual knowledge building. In grounded theory, interview transcripts are organized by codes, and relationships linking the codes are used to interpret the results in the context of the broader question [4].

The author created the MARVLS App and developed the visualizations to scaffold student conceptual understanding. They also teach with the MARVLS App in their courses, and conduct the interviews of the participants. Despite setting aside preconceived ideas, the author will have some biases about how students are incorporating knowledge gained from using the App as they build their conceptual understanding. The benefits of being the researcher include the author knowing the App in great detail, having designed the AR models and interactions to help students integrate 3D visualizations, 2D representations, and gestures such as the right-hand rule into their resources to strengthen conceptual understanding. Charmaz's version of grounded theory assumes that the researcher will bring their own experiences into the research process and recognize the resulting weaknesses and strengths [5]. Charmaz developed constructivist grounded theory with a focus on how participants construct meaning in relation to their experiences. The researcher constructs the theory with their view of the world. In this grounded theory study, videos were used to record the interviews with students. The over-the-shoulder video provided insight into how the students were using the App and viewing the model. Their descriptions of the concepts and what they observed in the App were coded. Gerund (sentence segment) snippets were compared and coded. In the theoretical sampling phase, interview participants were recruited with varying prior knowledge of the physics concepts. Snippets from these interviews were compared to the snippets and codes of the physics students. Theoretical saturation was reached as the interviews with new participants did not generate new codes. Axial coding provided the categories that were generated from the codes.

Motivation and research questions

Students often find abstract and 3D physics concepts challenging to grasp [6]. While instructors employ hands-on physical demonstrations and simulations to aid understanding, these methods have notable limitations. For instance, hands-on demonstrations are typically conducted once, with limited interaction from students. Similarly, simulations may not provide a realistic visualization of 3D objects, especially without real-world context.

AR technology emerges as a promising solution to these limitations. An AR application allows students to interact with 3D models directly, holding and manipulating them in their hands. This immersive experience enables students to explore models from multiple perspectives and interact with the models as often and for as long as they need to facilitate a deeper understanding of physics concepts.

Students often understand a concept in the context in which it was presented to them. Many abstract and 3D concepts are taught using 2D representations, and students may not consider the models from other perspectives. The 2D representation is chosen to convey the most information, but the concept may not be recognizable to students from a different view. For example, students may not recognize that the same magnetic field can have different 2D representations as dots and X's or as arrows as shown in Figure 2. The AR model allows students to view the magnetic field from every direction, add 2D representations into the model, and interact with the model, as shown in figure 2, where a student is using the right-hand-rule to see how it matches with the current and magnetic field in the model.

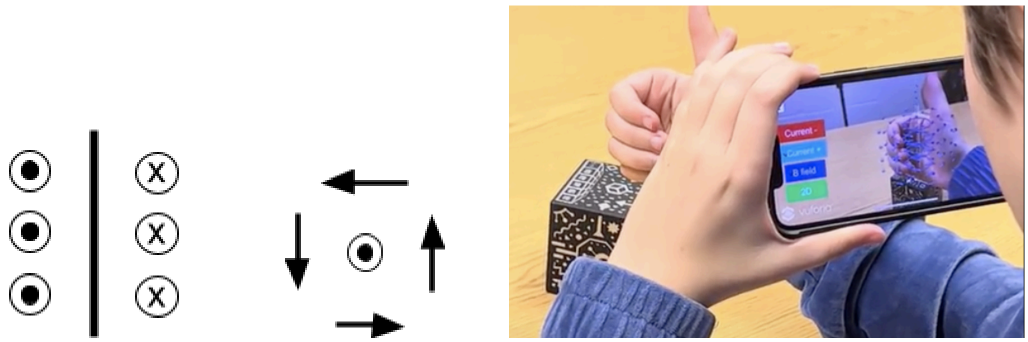

Figure 2. (a) Side view (b) top view (c) 3D view in AR

Methodology

In an IRB approved study, students were interviewed about their understanding of the model of a magnetic field surrounding a long wire. They were first asked to explain what they knew about a current carrying wire, then prompted to interact with the app and explain what they saw. This was followed by a small break to discuss unrelated coursework or job prospects to step away from the subject. Finally students were asked again to explain their understanding of the concept and what they learned through interacting with the app. Video recordings of the interviews were taken from the front and over their shoulder. The videos taken over their shoulders gave a view of what the students were seeing in the App, how they were interacting with the buttons, and when they were using gestures as they described their experience using the App. The view from the front provides facial cues for recognition or confusion. These videos were assessed to see what sort of terminology and hand gestures the students used to describe what they knew and saw.

Data collection and analysis

The videos were transcribed, and the language the students used to describe the AR model was recorded. Gestures students used and interactions with the app were recorded in the videos taken over the shoulders of the students to show the student view of the model. This made it possible to keep track of how much the student interacted with the model, including how much they held the cube, rotated the cube, changed their view of the AR model with the cube or with their phone, when they turned on the current, magnetic field, and 2D representation with buttons, and how they used the button connecting the 2D representation to the model.

The outcome of this grounded theory study will guide the modifications that will be made to the app in the areas of the magnetic field of a current-carrying wire, user engagement through the UI experience, and changes to the accompanying lesson to optimize student understanding and confidence in their knowledge of the concept.

Results and discussion

Codes were grouped through the axial coding process into the following categories:

- Concepts students easily understand through use of the model
- Concepts students learn/solidify through exploring the model
- Concepts students do not initially understand
- Concepts students do not connect, despite use of the model
- Student interactions with the model: useful/unuseful

Concepts students easily understand through use of the model

Many of the components of the AR model and the UI interactions, such as the buttons, result in students learning the magnetism concepts as expected. One example in the AR model that students readily recognize is that the vectors representing the magnetic field are straight and that the length of the vectors are related to the strength of the magnetic field. A second example connects the 2D representation of the magnetic field of a current-carrying wire to the 3D model. When a button is pressed, the 3D arrows that are represented by dots and x's in the 2D representation are highlighted in green. At the same time, the dots and x's in the 2D image also turn green. Students readily make these connections, even if they have not learned about 2D representations previously.

Concepts students learn/solidify through exploring the model

When viewing the 2D representation of the current-carrying wire (see Figure 2a), some students will describe the dots and x's as current or positive charges and negative charges. When the student presses and holds one of the buttons in the app, the arrows in the 3D model are highlighted, and the x's and dots on the button they are pressing turn green. Students are asked to describe how the 2D representation and the highlighted arrows in the 3D model are linked. This exploration gives students the opportunity to correct their understanding of the meaning of the dots and x's and to see that they represent arrows into and out of the page.

Some of the participants came to the interview with a solid understanding of the magnetic field of a current-carrying wire. When asked to describe what they saw in the AR model, they took the opportunity to view the app from multiple perspectives. They rotated the cube and made close observations. Students start the interview with a translucent cylinder oriented vertically. The current is represented by small blue positively charged spheres traveling up the cylinder. The magnetic field is represented by arrows tangent to a circle where the arrows are longer close to the wire and shorter further away. These students described the current while picking up the cube and bringing it close to the phone to zoom in. They rotated the cube to see the arrows around the wire. They also rotated the cube toward themselves to see the current coming at them and to support their description of the magnetic field circling in a counterclockwise direction.

Concepts students do not initially understand

Some students with prior knowledge about the magnetic field of a wire had misconceptions. For example, they did not know that by convention, current is the movement of positive charges in a wire. Nor did they know that the thumb points in the direction of the magnetic field when using the right-hand-rule. Some students used a different right-hand-rule, and because they were expecting three vectors, added that idea into the model and stopped calling the arrows the magnetic field. They sometimes referred to the arrows as force and other times as electric field. They became very confused and reverted back to generic descriptions like arrow and vector. Many students said that the magnetic field circles, flows, rotates, or swirls.

Students were able to clear up some of these misconceptions. Once the student was reminded of the correct right-hand-rule, they went back to calling the arrows the magnetic field, and viewing the model, they moved to a more confident understanding of the magnetic field of a current-carrying wire.

Other misconceptions, such as electron flow versus the flow of positive charge and how that relates to current, continued to be confusing, but the AR model allowed the students to eventually realize that the current and the right-hand-rule apply to positive current and positive charges moving upward. The misconception that the magnetic field is rotating was not cleared up in the App. While the arrows representing the magnetic field weren't moving, students did not make that connection.

Concepts students do not connect, despite use of the model

Some students interviewed using the App failed to connect the components of the model with the magnetism concepts they represent. This was illustrated when their descriptions didn't progress from describing little blue spheres moving upward to using the name current or from their descriptions of arrows to using the name magnetic field. The names that were used included words like it, arrows, vectors, cylinder, dots, and x's.

Some students started out calling the arrows magnetic field, but when they became confused, they would return to using words like arrows and vectors for the magnetic field.

Student interactions with the model: useful/unuseful

As described above, students brought the cube close to their phone to zoom in on the AR model. They rotated the cube to view the current coming toward themselves and to observe or confirm that the magnetic field was directed counterclockwise. Some students held and pressed the 2D button to see the green arrows and noticed the changing color of the arrows, and they nodded and confirmed that their descriptions of the model were matching up with their conceptual understanding.

An example of an unsuccessful interaction was when a student used the wrong right-hand rule and added concepts that were not present. This resulted in a student suggesting that the magnetic field was actually the electric field. This also resulted in the student no longer describing the arrows as the magnetic field and instead describing them more generally as arrows or vectors. Another unsuccessful interaction was when a student did not rotate the cube to view the AR model from other perspectives. The student only viewed the model when the 2D representation was lined up with the 3D model. This was problematic as the student was suggesting and asking questions about how the 3D model matches up without rotating the model to see different views that would provide more information about the concept.

The foundational grounded theory developed from these categories is:
Student conceptual understanding improves with guided inquiry using a 3D AR model.

Conclusion

A qualitative study was performed using a grounded theory methodology to identify how students use an augmented reality model smartphone app to learn about or reinforce their understanding of the magnetic field of a wire. The combination of interacting with the 3D visualization, connecting the 2D and 3D representations, and incorporating the right-hand-rule gesture into the model augments student understanding.

The results of the study provides guidance for improvements to the 3D AR model and the accompanying lessons that guide students as they use the MARVLS App. For example, including the option to select both positive and negative current in the model created confusion for students. The option to select a negative current will be removed from the existing AR model and a new AR model representing positive and negative current will be added to the App. New lessons will include activities that invite students to rotate and view the AR models, guide students to draw the AR models from different perspectives, and ask students to draw 2D representations of the AR models.

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