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# Embodied Learning with Gesture Representation in an Immersive Technology Environment in STEM Education

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# Embodied Learning with Gesture Representation in an Immersive Technology Environment in STEM Education

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## Abstract

Students struggle with developing conceptual understanding of abstract concepts in Science, Technology, Engineering, and Mathematics (STEM) courses. Two-dimensional (2D) figures are commonly used during instruction in textbooks and multi-media presentations such as PowerPoint, or in computer animation. The use of 2D visualizations during instructions lacks opportunities for students to meaningfully explore these concepts by rotating three-dimensional (3D) visualizations and examining how the rotations impact the 2D representations. Instructions delivered using 3D visualizations have the potential to improve conceptual understanding of both concrete and abstract concepts. In this study, we employ a multiple case study methodology to examine student gestures to explore how the use of augmented reality in an immersive technology environment can impact conceptual understanding of abstract concepts in STEM education. Preliminary findings indicate that students utilize gestures that represent the visualizations in the AR application to think and reason about abstract concepts such as electric and magnetic fields. In addition, these gestures appear to be related to mental simulations that students employ during problem-solving. The benefits of employing innovative pedagogical approaches through correct gestures, visualization and cueing representations is not limited to improving conceptual understanding in STEM but promote problem solving and critical thinking. The benefits derived from integrating gestures and 3D visualizations in AR immersive technological environments suggest that using embodied learning activities have strong potential for abstract conceptual learning in STEM.

## Introduction

Learning within STEM entails developing conceptual understandings and theoretical models involving concepts with complex interactions between visible objects and unseeable constructs and forces. This is particularly true for topics like Electricity and Magnetism (E&M) that involve abstract and non-visible phenomenon. For courses like this, students need to develop mental models that represent the three-dimensional (3D) relationship between physical objects (e.g., wires or batteries), non-visible objects (e.g., electron movement), and abstract conceptions (e.g., magnetic fields, current). In addition, success in E&M requires strong spatial reasoning to rotate each mental model to solve problems, and representational fluency to coordinate between their 3D mental models and the two-dimensional (2D) representations commonly used in E&M courses. These skills may be one of the reasons that most students' understanding of E&M is fragmented and lacks a coherent understanding of the phenomena [1,2].

E&M is a required course for most science, engineering, computer science, and pre-medicine majors, so it is critical to learn how students develop the spatial reasoning and representational fluency skills needed to develop models that visualize interactions between charged particles, electric and magnetic fields, and other unseen or abstract topics. Because these models are built upon in other courses as students' progress through their majors, it is also critical to understand how to best scaffold instructions for students to ensure robust and enduring mental models.

Theories of embodied cognition view cognitive processes such as thinking and learning as being grounded in bodily actions and systems of perception, as well as brain functioning. As such, the development of conceptual understanding for the type of abstract concepts found in E&M would benefit from education that engages students in interacting with conceptual representations through embodied interactions. Advances in digital technology, particularly in devices that allow for augmented (AR) and virtual reality (VR), now allow students to directly interact with abstract and non-visible concepts such as magnetic or electric fields. This study examines how students develop mental models using a free AR app (MARVLS) to interact with E&M concepts using everyday technologies, such as smartphone or tablets. As such the research question examined is: *How does using an AR app to explore E&M topics impact how students use language and gesture to describe and reason with the mental representations of the E&M topics?*

## Spatial Reasoning

Spatial reasoning is generally defined as the ability to perceive spatial relations among objects in space, the ability to generate, manipulate, memorize, and reason with images and mental models constructed from the spatial relations of their components, and to utilize these mental models to solve problems [3,6]. The ability to think and reason with abstract concepts in STEM requires students to visualize and manipulate interactions in 3D, mentally simulate objects, forces, and fields, represent these interactions in mental models, and the translate these representations across multiple modalities [3,7-9].

The ability to mentally rotate and animate mental representations, and to represent 3D objects with 2D representations are highly correlated with entry into STEM fields, performance in STEM courses, and persistence with STEM majors [10-14]. However, many college students struggle with spatial reasoning [9,15-17], which has led cognitive psychologists to conclude that poor visuospatial skills represent one of the true barriers for success in STEM fields [18]. Because spatial reasoning is rarely a learning outcome in pre-college education [4,19], the disparity in spatial reasoning directly impacts diversity in STEM [16,17,20]. While spatial reasoning skills can be learned through training [18] and experience with physical and virtual manipulatives [21-23], advances in technology allow for the overlay of visualizations onto the environment which can help students improve their mental simulation without the need to purchase physical manipulatives [24,25].

## Embodied Learning

Theories of embodied cognition assert that the cognitive processes of thinking and learning are grounded in bodily actions and systems of perception, as well as brain functioning [26-30]. While the exact mechanisms underlying cognition from an embodied perspective are still being debated; all theories agree that thinking and reasoning originates in bodily interaction and is internalized as simulated action [30-32]. This interaction between brain and body means that mental representations and conceptual understandings are grounded in movement within and interactions with social and physical environments [33,34]. At the same time, mental representations, and conceptual understandings impact what perceptual stimuli we attend to, how we interact with our environment, and how we ascribe meaning [35,36].

Activities that encourage learners to make explicit connections between physical movements and interaction and target conceptions constitute *embodied learning* [37], and several recent studies have demonstrated positive effects in STEM learning [33,38,39]. AR technologies can overlay digital representations of unseen objects and abstract conceptions onto personally relevant environments. This makes AR very promising for teaching STEM content while also developing spatial reasoning and representational fluency.

## MARVLS AR Platform

The MARVLS App is an AR app for students to explore representations of abstract E&M concepts. MARVLS is a free app that can be downloaded to any smartphone or tablet. Students use a Merge Cube [40], or a paper version, to digitally place models of the E&M concept that students can then physically manipulate the cube to examine how the 3D visualization changes and explore the relationships between the model components (Fig. 1 – 2).

**Fig 1**. 3D model of a magnetic field surrounding a current-carrying wire with the associated 2D representation in the grey box (Left). When students touch the 2D representation, the 3D model is augmented adding green arrows to highlight the magnetic field at the 2D plane.

MARVLS provides opportunities for students to reflect on interactions with the physical cube and digital model by allowing students to rotate digital model by rotating the cube. This allows students to manipulate aspects of the digital models by modifying current flow, shape of components, and orientation of the system to explore complex interactions between objects and fields. Activities then scaffold students to map these interactions to formalisms, such as Lorentz forces, Gauss's Law, and Ampere's Law, as well as abstractions, such as mathematical equations like Maxwell's equations. By connecting equations and formalisms to a variety of actions grounded in conceptual metaphors and intuitive understanding, MARVLS facilitates conceptual learning while preserving equity in interactions.

**Fig 2.** Students using MARVLS to explore E&M conceptual models.

MARVLS has been used in Physics Courses at a small two-year college located on the east coast to teach E&M. A pilot study using an E&M assessment developed by [40] which demonstrated students showed learning gains on a post-test after using MARVLS to learn E&M in their course, with larger learning gains for students with the lowest pre-test scores. In addition, in-class observations revealed that students engaged with the AR app in different ways. The diversity with which students interacted with the MARVLS indicates that there is a need to explore how students engage with MARVLS, and the how using MARVLS to explore E&M topics impact how students describe and reason about E&M topics.

## Methods

This study utilizes a case study design, where two participants were interviewed to uncover their conceptual understanding of magnetism and electromagnetism. This qualitative study utilizes two individuals because these cases "provide reliable indications for the directions" of augmented reality interventions for improving conceptual understanding in engineering education [41, p. 428]. A case study is an empirical investigation of a phenomenon conducted in its natural settings with the intent of drawing conceptual implications for a broader study base on its findings [42]. The cases presented in this study were selected from a larger interview study conducted at a small two-year college located on the east coast. To examine how students incorporated the experience of using the MARVLS app into their mental models for E&M concepts, participants who had been exposed to the content, but did not have a complete canonical conceptual understanding were needed. Participants who had taken Physics in high school and were Psychology majors were recruited to complete a one-hour interview involving a pre-test where participants were asked to explain the relationship between electric current and magnetic fields, the relationship between moving charged particles and magnetic fields, and electromagnetic induction. Interviews were completed in the research lab of the third author, and videos were taken from the front and rear of the participants to capture both their interactions and gesture, as well as the screen displaying the AR visualizations. All participants consented to allow screen shots of the interviews used for publications.

For this analysis, we examined two cases (Kasey and Samira) as they interacted with the MARVLS simulation that explored the relationship between electric current and magnetic fields. The two cases were selected because the participants remembered learning about the above E&M concepts, could not remember any details about the E&M concepts, and had no experience using AR. Both participants were first-year female college students and had taken Physics in high school. Participant gestures and verbal explanations were examined for evidence that the participants consented to participate and have screen shots of the interviews used for publications.

## Results

At the beginning of the interview both participants were asked to imagine current moving through a straight wire, and were then asked to describe what the magnetic field might look like as a result. While both participants indicated that they could not remember the answer from their physics classes, Kasey demonstrated a speech-gesture mismatch. Gesture-speech mismatch reveals a transitional state of learning and is labeled discordant by cognitive psychologist, this indicates that the learner is receptiveness of prior instruction and requires a series of questions or instructions to address this problem. [43] Kasey verbally indicated, “Isn’t it just the opposite ... No, it’s not the opposite way. Its um something like… I don’t know?” However, while she was saying this, she made a loose fist with her right hand while pointing her thumb upwards (Figure 3a) reminiscent of the Right-Hand Rule which indicates how a magnetic field curls around a current carrying wire. This gesture may have represented implicit knowledge that Kasey had access to but could not verbalize.

**Fig 3.** Kasey (a) describing the relationship between current and magnetic field, (b) describing the direction of the arrows in the MARVLS app, (c) manipulating the Merge cube, (d) describing the direction of the magnetic field, (e) describing the relationship between current and magnetic field.

The participants then were asked to explore a simulation using the MARVLS app where the user can view the current in a wire and the induced magnetic field (Figure 4a). Both participants viewed the wire as a tube and the current as spheres moving through the tube. They used the buttons on the app to get the current (i.e., the conventional current represented by red dots) to move upwards, then turned on the magnetic field which was represented by blue arrows. When the participants were asked, “What do you notice about the arrows?” Samira indicated that “they were going around the current, the cylinder.” Kasey similarly described the arrows as, “going to the right like in a circle.” This attention to the direction was critical for Kasey as she manipulated the cube as she noticed that as she rotated the cube 90 degrees (Figure 3b) that “the arrows are moving as I turn the cube, but its [direction of the arrows] to the right.” In addition to the direction of the arrows, Samira noticed that the sizes of the arrows closer to the cylinder were longer, while the ones further were shorter. When she was asked what she thought this meant, she replied that “closer are stronger…the more further the current is to something is like it is more stronger”.

As the participants continued to manipulate the cube (Figure 3c), the location of their gestures shifted, which indicates that the learners are moving from a discordant state to a concordant state [44] of understanding the more questions are asked, the more orientation of the cubes and engagement in the embodied augmented learning environment at the beginning of the interaction with the MARVLS app, both Kasey and Samira gestured gestures behind their phones (e.g., Figure 3b). However, as the participants physically manipulated the orientation of the cube, and therefore the visualization, they began making gestures in front of their phones and near the cube (e.g., Figure 3d). This shift in gesture location appears to indicate that the participants stopped seeing the visualization as a part of the screen and began seeing the visualization as a physical manipulative. At the same time both Kasey and Samira began to describe the relationship between current and magnetic field in a more nuanced manner, indicating that the shift in gesture may also indicate the integration of the visualization into their mental models.

Fig 4. (a) The MARVLS simulation exploring the relationship between electric current and magnetic fields, (b) screenshot of the simulation with the 3D and 2D representations, (c) when the user touches the 2D representation, the arrows on the 2D plane are highlighted.

Once Kacey and Samira started to understand the relationship between current and magnetic fields, they were asked to touch the 2D button question mark (?) in the lower left-hand corner of the MARVLS app. This button incorporated a 2D representation into the 3D visualization (Figure 4b). When the participants touched the 2D representation in the lower right-hand column the arrows representing the magnetic field in the plane of the 2D representation were highlighted in green (Figure 4c). When the participants were asked how the 2D picture relates to the 3-D model, Samira reported that the “circles are different representing the direction they are going”, the circle with a dot represents “going towards me” and the circle with an ‘x’ “going away.” Kasey, on the other hand, had difficulty relating the direction of the arrows to the dot and x representation. However, Kasey did correctly intuit that the dot and the x represented opposites calling the dot positive and the x negative.

After having Kasey and Samira explore the MARVLS application both participants were asked, “If I were to tell you one of the things we learn in physics is if you point your thumb in the direction of positive current. Your fingers represented the magnetic field. Can you make sense of that with that [Cube]?” Both Kasey and Samira were able to reason that if a person were to use their right hand and point their fingers in the direction of the conventional current, that their fingers would curl in the direction that the magnetic field points. This is evident in how both participants demonstrated the correct gesture of the Right-Hand-Rule for a current carrying conductor to support the explanation for the direction of the magnetic field. When learners demonstrate gesture-speech match, this is evidence of a profitable instruction [45]. Kasey and Samira demonstrated that engaging in an embodied learning environment through the MARVLS application provide evidence for conceptual learning throughout their experience using the MARVLS app. Both their gestures and explanation were coherent with the principles of electromagnetism, which provides some evidence that participants were using MARVLS to build a mental model and scaffold their spatial reasoning in manipulating the mental model as the direction of the current changes. The reasoning displayed by both Kasey and Samira demonstrated that they are beginning to gasp the spatial relationship that underlie the physics phenomenon.

## Conclusion

Both Kasey and Samira successfully interacted with the MARVLS app to develop a more canonical understanding of the relationship between current and magnetic fields. Unsurprisingly, this conceptual understanding required scaffolding. Kasey and Samira were able to describe the components of the 3D model by describing the shapes (e.g., cylinder, spheres, arrows), however they needed the interviewer to provide them with the formal vocabulary for the concepts. However, once the formalism was provided to the participants, they incorporated this vocabulary into their models. This result is consistent with embodied pedagogical strategies that begin with exploration of physical interactions followed by teaching of formalisms [46].

Two important observations support the conclusion that students integrate the visuals from the MARVLS app into their mental models. Firstly, the participants changed the location of their gestures from behind the phone to on the cube after interacting with the cube. This suggests that the participants began by viewing the visuals as part of the application. However, after seeing the visualizations change as they interacted with the cube, the location of their gestures shifted to on the cube. This suggests that the participants began to view the visualizations as the objects that they were manipulating. Secondly, after using the MARVLS app the participants were asked to imagine that their thumb represented the direction of the current and asked to describe what their fingers might represent. Both participants immediately pointed the thumb on their right hand upwards and curled their fingers. They explained that their fingers would represent the magnetic field. This suggests that the participants were able to translate their mental models to a physical representation, in this case the common Right-Hand Rule gesture.

Finally, when Kasey was initially asked to describe the relationship between current and magnetic fields, she verbally indicated that the magnetic field might be in the opposite direction from the current, then rejected this idea before saying she didn’t know. At the same time, she pointed the thumb on her right hand upwards and curled her fingers. This gesture was not similar to any other gesture she made before interacting with the MARVLS app. This suggests that Kasey may have had implicit understandings about the relationship between current and magnetic fields but was not able to access or manipulate this mental model. This finding is similar to research indicating that body movement and gestures may represents either tacit knowledge or knowledge in transition [42,44, 46]. In addition, prior research has found that students’ knowledge is often reflected in their gesture and plays a role in how thoughts change over time [47]. Our study extends this research as speech-gesture matching was observed in this case study with undergraduate students.

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