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How Augmented Reality Transforms Learning and Inquiry Patterns in 1-1 Remote Tutoring

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Abstract: Augmented reality (AR) technology is being considered by educators for its proven ability to help students visualize abstract concepts; however, currently there are barriers to having this technology available for every student. In this study we investigate the use of AR in remote 1-1 tutoring scenarios, which can be more accessible and affordable to educational institutions since AR devices would not be required for every student. We present a system for AR-based physics instruction, and perform a between-subjects study where an instructor uses the AR system while teaching electromagnetism physics to a remote student. The two experimental conditions differ in the types and amount of AR visualizations. We measure how the presence of AR impacts student learning and inquiry activities. We find that students who are tutored with more complex AR content have better learning gains and make more requests for action, compared to students who view the same lesson with limited AR. We discuss possible reasons and implications for these findings.

Introduction and Related Work

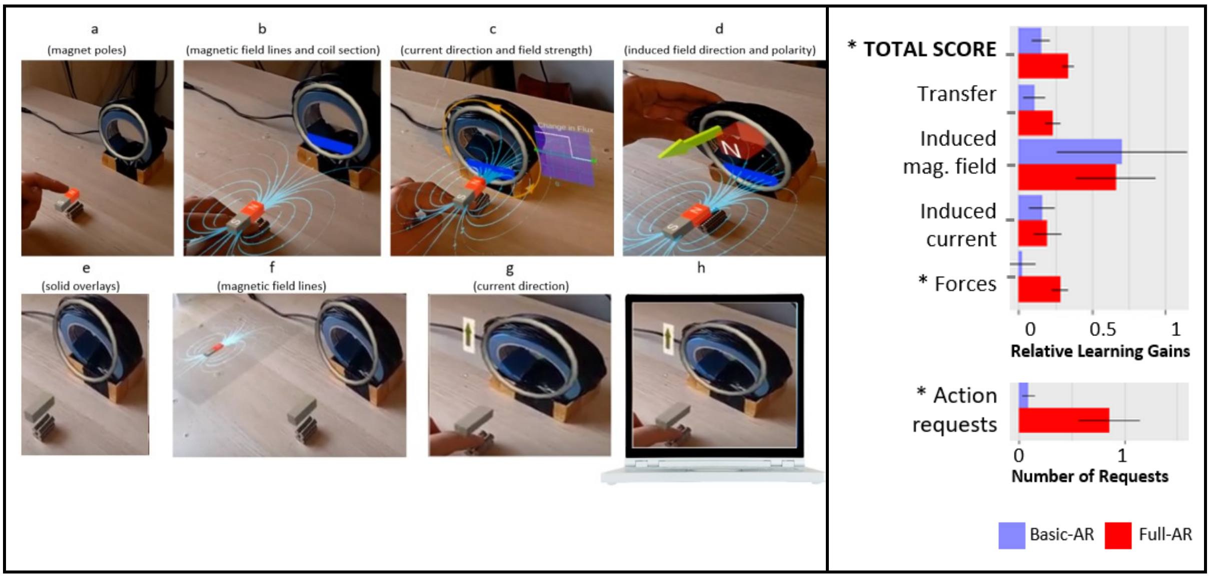
Augmented reality (AR) technology is becoming known to many educators due to its potential to visualize complex 3D phenomena and increase student engagement (Arici et al., 2019), and there is growing enthusiasm about integrating AR into educational settings (Akçayır & Akçayır, 2017). However, this enthusiasm is limited by multiple factors, such as the high cost of providing AR devices for each student and creating AR content that is interactive and personalized, as well as barriers to entry due to limited student knowledge of AR technology (Radu et al., 2021). In the present research we investigate the use of augmented reality for the underexplored purpose of 1-1 tutoring, specifically in the context of online tutoring. We investigate the context where an instructor is using an AR headset while manipulating physical objects, while working with a student who views the instructor's view remotely through a computer screen (Figure 1 a-h). We envision this context will become popular with educators because it can reduce multiple limitations: personal AR devices for students would not be required, instructors would be able to illustrate learning content through carefully curated AR activities, and students would still be actively engaging in the investigation of the learning material without special knowledge of how to actively control the experience. Through a novel AR system and a controlled study comparing the impact of augmented reality visualizations in 1-1 tutoring of physics, we investigate the effects of AR technology on student learning gains, and on students' inquiry and communication processes.

Previous studies have shown that active engagement of students increases learning (Keithly et. al., 2015; Mayer et. al., 2003), and keeping students active has become a general educational recommendation, especially in the context of multimedia (Brame, 2016). Furthermore, using multimedia to present educational content as external representations has the power to enhance learning and communication (Ainsworth, 2008). Therefore, in a more active and representationally rich context such as augmented reality lessons, one might expect more effective learning to take place. Indeed, in the domain of physics, studies on students use of AR devices have shown that AR can improve understanding of magnetic fields (Abdusselam & Karal, 2020; Cai et al., 2017), electromagnetism concepts (Ibáñez et al., 2014; Radu & Schneider, 2019), and circuits (Beheshti et al., 2017; Bellucci et al., 2018). Typically AR education research has studied settings where students learn individually or collaboratively with peers. However, there is a lack of research about AR-enabled 1-1 knowledge exchange between students and instructors. Furthermore, comparative studies of AR learning typically compare AR instruction to non-AR traditional instruction such as paper-based or computer-based learning, but do not control for the effects of technology novelty on student motivation, and typically information exposure varies widely between AR and non-AR conditions. In this present study, we specifically look at the context of AR in 1-1 remote tutoring, and control for the effects of novelty and information exposure, by executing a controlled study where subjects in both conditions are exposed to AR overlays on physics objects, while the information provided by the instructors is designed to be similar between conditions. We hypothesize that more complex AR visualizations will improve learning by increasing students' active engagement and deeper inquiry processes. We expand on this literature by investigating how AR influences students in the context of 1-1 remote tutoring with an experienced instructor. We specifically investigate the research question of: *How does the presence of AR impact student learning during remote tutoring ?*. To answer this question, we have designed an interactive AR system for remote 1-1 tutoring, and performed a between-subjects study that measures learning and inquiry through quantitative and qualitative methods.

System and Study Design

We designed and implemented an AR system that instructors can use to teach the electromagnetism concepts of Faraday's Law and Lenz's Law, which describe how a moving magnet induces an electric current and opposing magnetic field in a nearby coil of wire. The user study was designed as a between-subjects design with one independent variable (amount of educational AR, containing 2 conditions, Full and Basic, described below), and dependent variables of learning gains and action requests. A total of 44 adult students participated in the study (N=22 in each condition, randomly assigned), recruited from introductory physics classes at a university in the United States, who had recently attended at least one class lecture introducing the concepts of Faraday's Law and Lenz's Law. Participation did not count for course credit, was voluntary, and occurred outside of class. During the experiment, participants talked with the research instructor through Zoom video-conferencing, for a duration of approximately 75 minutes. The experimental procedure consisted of a 15 minute pre-test (administered through an online Google form), 35 minute instructional activity, 15 minute post-test, and post-interview for the remaining time. For the instructional activity, the instructor wore a Microsoft Hololens 2 AR headset and shared its view on the shared Zoom screen visible to the student (Figure 1.h). Students could see the same view as the instructor. The system showed dynamic 3D visualizations overlaid on a physical magnet and coil (Figure 1.left). The instructor could choose various AR visualizations during the instructional session, and could enable, disable, and move visualizations to answer questions. Furthermore, the visualizations dynamically changed with the movement of the magnet, and simultaneously with each other, to show students how multiple physics concepts are interrelated.

Figure 1. Left: *Visualizations shown from the perspective of the instructor, in Full-AR condition (a,b,c,d), vs. Basic-AR condition (e,f,g); and student's view on their computer screen (h). Brackets: Names of AR visualizations.* **Right:** *Relative learning gains and Action Request questions, average per session under each condition. N=44. Bars=std. error. *=sig. p < .05.*



Participants were exposed to instruction through either a high amount of AR visualizations ("Full-AR"), or a low amount ("Basic-AR"). These conditions were designed to measure the effect of dynamic AR visualizations during tutoring, while controlling for extraneous factors. In order to control for increases in student excitement due to exposure to novel technology, both conditions contained AR visualizations. Furthermore, the conditions were similar in terms of the instructional material taught to students, and the number and types of question prompts given to students during the activity. One researcher acted as the instructor in all sessions. In both conditions, students were told they could interrupt and ask questions at any time, and the instructor presented the educational materials in 3 sequences, explicitly asking the students if they had any questions at the conclusion of each sequence. The instructional activity script was designed to teach the same instructional content in both conditions even though the instructor showed different kinds of AR visualizations; the only difference in the script was when the instructor referred to specific visualizations. The differences between conditions were in the types of AR visualizations shown to students: The Basic-AR group saw simple static visualizations (a virtual block overlaid on the physical magnet and a virtual coil on the real coil (Figure 1.e), and a static virtual depiction of magnetic fields on the desk (Figure 1.f), and a dynamic visualization of electric current direction (depicted as an up/down arrow near the coil (Figure 1.g)); this information could have been accessed during traditional instruction through tools such as a voltmeter for measuring current direction, and a drawing to show magnetic field lines. In contrast, the Full-AR group saw enhanced visualizations (Figure 1. a,b,c,d).

Learning was measured through pre- and post-tests containing questions about Faraday's Law and Lenz's Law, typically involving relationships between magnet movement, electric current, and forces. The test also contained transfer questions, measuring students' ability to transfer knowledge to situations beyond what was covered in the activity. The learning metrics were calculated using relative learning gains, which accounts for the fact that a participant's score will not increase as much when they already know a lot before the study, and is calculated as the ratio between actual improvement and the total amount of possible improvement: (post score – pre score) / (max achievable score – pre score). Statistical differences between conditions on learning gains were calculated using T-Tests. We also performed qualitative analysis to understand how often a student makes a request for action. An "action request" count was increased every time the student explicitly requested the instructor to take an action. For example, "Can you pick the magnet up off the table, please?", or "Can you pull it again?." or "Let's see it if you flip the magnet!". Statistical differences between conditions on action requests were calculated using Mann-Whitney-Wilcoxon test.

Results

The **starting knowledge** is believed to be equivalent between the two conditions, since participant pretest scores did not significantly differ between Full-AR and Basic-AR conditions ($t(20) = -.37$, $p = .71$). Relative learning gains scores resulting from the activity are shown in Figure 1 (right). **Overall learning** of Full-AR participants was significantly higher than Basic-AR participants by nearly a factor of two ($t(20) = 2.20$, $p = .035$). Analysis of specific dimensions of the learning test revealed that Full-AR groups scored significantly higher on questions about physical **forces** ($t(20) = 2.31$, $p = .027$), possibly due to forces being depicted as dynamically changing AR arrows. Descriptive statistics also show that Full-AR groups tend to score higher on ability to **transfer** knowledge to new situations, while Basic-AR tend to score higher on questions about magnetic field **induction**. When observing how students made **action requests**, we detected that Full-AR participants made significantly more action requests (roughly 10x higher; $W = 313$, $p = .010$) than Basic-AR participants.

To better understand the participants' subjective experience, we collected information through semi-structured interviews at the end of the study. These lasted 15-20 minutes, and covered questions such as "How do you feel about our activity today?", "How does this compare to how you currently learn in class, or in office hours, or in labs?", or "Is there anything you want to change about this activity?". We observed different trends from responses between the conditions. Both groups appreciated learning through the AR visualizations and interacting with the instructor through 1-1 tutoring; however, Full-AR participants discussed virtual objects more frequently, and mentioned that the interplay between visuals was especially useful in helping them understand the concepts. In contrast, Basic-AR participants mentioned that compared with the textbook and more traditional online 2D simulations, being able to see the real objects like the coil and the magnet in the three-dimensional real environment was helpful. In terms of communication, Full-AR participants emphasized that AR visualization helped reduce the misunderstanding when discussing abstract concepts. When talking about the improvements, nearly all Full-AR participants expressed their interests in manipulating the visualizations by themselves; in contrast, this was rarely mentioned among Basic-AR participants, and mirrors the findings about action requests discussed above.

Discussion

In this study we explored the efficacy of using AR for 1-1 tutoring, where the instructor wore an AR headset while the student remotely observed the AR view. This style of tutoring might become popular because it is instructor-led and students will not need individual devices, enabling easier integration into educational settings. Although participants in the high AR condition benefitted the most, it is worth mentioning that participants in both conditions reported increased excitement and perceived benefits, such as enjoying the 1-1 interaction and the ability to ask questions and clarify knowledge, increased their learning, and increased ability to guide the instruction. This style of AR-based remote tutoring has the potential to improve the accessibility of education, permitting students who are in remote or low-income environments to connect to quality instruction. Additionally, the fact that the tutoring session was done remotely through Zoom may have impacted students' overall sense of agency, by reducing their ability and willingness to control the learning activity.

We observed that access to dynamic augmented reality visualizations led to improvement in student learning. A higher degree of AR visualizations significantly improved learning, and significantly increased students' interest in requesting actions upon the learning content. While AR helped students learn better, the visualizations may have enabled students to more easily observe the effects of actions upon the system, thus encouraging more requests for action. Additionally, the presence of seeing multiple visualizations dynamically changing at the same time may also have provided students with knowledge about how concepts are integrated Although these results are descriptive in nature, this may indicate that AR representations serve to offload the cognitive work for the students. As students visualize invisible concepts through the AR visualizations, this may free up students' need to understand the content or perform mental simulations, and explains why students are more interested in exploring other possibilities, as observed through increased exploration in action requests. Future research can explore how AR visualizations serve to offload conceptual processing associated with understanding abstract concepts, and how student cognitive load can be mediated by AR representations.

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