Effects of Augmented Reality Enhancement on Students' Scientific Reasoning

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Abstract

Advances in augmented reality (AR) have been studied to supplement hands-on, physical labs. Via AR overlays of real-time energy flow graphs, were created to illuminate scientific insights throughout a pendulum experiment. Compared to the traditional lab, participants who experienced AR enhancement demonstrated a deeper understanding of energy concepts, demonstrating AR's potential to improve scientific reasoning while maintaining interest.

1. Introduction

Extended reality, or a blending of digital and real worlds, has been shown to improve the educational outcomes for K12 laboratory science, with studies primarily focusing on outcomes related to content knowledge, engagement, and motivation (e.g., Brinson (2015)). While these aspects of learning are important, scientific reasoning, or the ability to think critically, form theories, and evaluate conclusions based on data, is another key outcome of laboratory activities that may be influenced by extended reality and has not been as well studied.

The primary objective this study is to evaluate whether an AR-enhanced laboratory can increase scientific reasoning. Our research questions are as follows:

1. How does using AR materials affect participants' learning in terms of scientific reasoning?

2. Related Work & Contribution

Scientific reasoning is the acquisition and application of skills such as identifying questions, designing and conducting experiments, developing explanations, analyzing alternatives, and constructing and defending arguments (Singer et al., 2005). Bakri et al. created an AR worksheet with imbedded AR overlay videos to assist learners in scientific reasoning for an elasticity lab (Bakri et al., 2020). In contrast, we use AR as a tool, which can be used for a variety of comparison-based pendulum labs.

Meta-Representation can help students understand scientific reasoning. While traditional representations are presented post data-collection or physically separated from the experiment, AR allows learners to see representations in situ with the experimental procedure (Thees et al., 2020; Yu et al., 2022) which improves learning outcomes. In our experiment, we use graphical representations to highlight energy transformations and analyze how this representation helps students understand energy throughout the experiment.

3. Method

We developed an AR mobile application that uses a real pendulum (Figure 1) to visualize the energy transformations real time as participants collect and evaluate data. The first screen, or Data Collection screen, allows participants to view the pendulum through a camera, and AR overlays provide additional insights (Figure 2). For brevity, only the energy graph is highlighted here:

The energy graph shows the transfer of potential, kinetic, and lost energy as the pendulum moves in real time. This allows participants see the loss of energy over time due to outside factors such as friction, as well as the transfer of kinetic, potential, and lost energy as the pendulum moves back and forth.

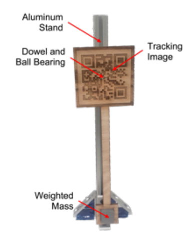

Figure 1

To obtain the real-time energy measurement, Vuforia was used to track both the orientation and position of the pendulum. The relative height of the pendulum could then be constructed via the cosine of the orientation from the vertical. The potential, kinetic, and lost energy could them be estimated from this relative height at the beginning and during the experiment.

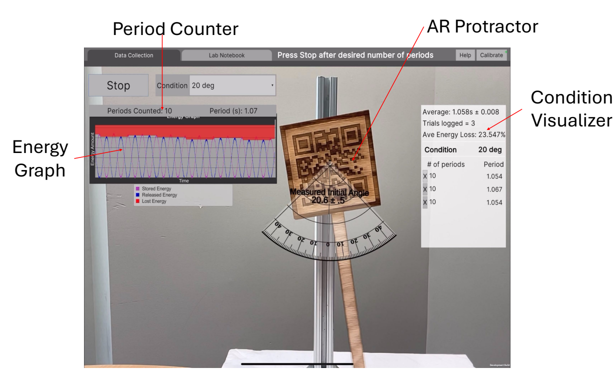

Figure 2

3.1. Experimental Procedure

Participants engage in the experiment in pairs in either the AR or control condition. After taking a pre-test on scientific reasoning, participants in the control group then conduct the experiments with a digital timer app and the physical pendulum. Participants in the AR group use the AR interface, and the physical pendulum. During the experiment, participants determine how friction and energy loss effects experimental results. They then conduct the experiment to determine if the measured period will change between recording one swing vs. ten swings when averaged over five trials. The second experiment asks learners to determine if the period is larger, smaller, or the same for ten degrees versus twenty degrees. After the experiment, participants complete a posttest and provide demographic information.

3.2. Analysis

While it is expected for the traditional lab to generate some learning of scientific reasoning, we hypothesize there will be significantly more learning with the AR group. To evaluate if the change in scientific reasoning was significantly affected by AR, we calculated the Bayes Factor to compare the following hypotheses:

H0: There is not an interaction between the AR group and pre-post test
H1: There is an interaction between the AR group and pre-post test

We also analyzed the responses the participants gave in pairs throughout the study, along with their free response questions to categorize differences between the AR and the traditional lab, such as energy observations.

4. Results and Discussion

We calculated a Bayes' Factor of 18.11, giving a strong preference for the AR condition. Therefore, the AR condition likely had an effect on the learning of science reasoning by the participants. We performed a standard effect size analysis (Cohen's d), analyzing the difference between the pre- and post-test scores. The standardized effect size is 0.63 ± 0.57, indicating that 73.47% of the control group is below the AR group's mean. By adding an energy graph to the interface, participants are given more information, and may have been able to develop more informed reasoning about their data. For example, some trials had a small energy loss, while others had a much larger loss. The energy graph allowed the participants to observe in real time the effects of outside factors on data collection, and how they could vary for each experiment. This may have contributed to their understanding of how uncertainty comes into play in each trial individually, and indicated to participants the importance of precision and the effects of uncertainty in evaluating experiments.

While students in both conditions in general understood the main idea of the lab (for large angles the period depends on the initial angle), students in the AR group were more likely to highlight the differences in the data, trust their data, indicate energy as a learned concept/surprising observation.

Participants were also asked what they learned, or if they observed anything different from expected at the end of the posttest. Those in the AR group were twice as likely to mention energy and its effects on an experiment. This is most likely due to the influence of the energy graph and calculations presented to the participants in the AR group, allowing them to focus and retain information from the data analysis better than those in the control group. However, participants in the control group were 55% more likely (14 control participants vs 9 AR group participants) to report how the lab helped them to understand the nature of experiments in a physics context. This may be due to the lack of technology included in the control condition, which required participants to be more precise, and therefore felt more similar to the precision and dedication necessary in a lab context.

5. Conclusions and Future Work

The AR-enhanced lab explored the use of augmented reality to teach scientific reasoning in a physics laboratory experiment. The results indicate that the AR lab improved participants' scientific reasoning skills. The AR interface may have allowed participants to focus more on data analysis and interpretation, leading to a better understanding of measurement error and the acceptance of experimental results

However, it is essential to consider the limitations of this study, such as the controlled lab. It is possible the observed effects may not replicate in a less controlled environment (i.e., a science lab classroom). Additionally, it is important to note that many of the learning effects were not retained when participants took a retention test two weeks later.

Future research could explore the impact of AR with different populations, such as participants with varying levels of prior physics knowledge and experiences, could provide valuable insights into the broader applicability and effectiveness of AR materials in science education. Further research in this area could contribute to the development of innovative and engaging educational tools that enhance participants' learning experiences and foster a deeper understanding of scientific concepts.

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