Students' attitudes on Project STEMinAR: Augmented reality in Physics

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Project STEMinAR is an augmented reality (AR) interactive simulation for use in the Physics classroom. The simulations topics include force and motion, Newton's cannon, optics, lenses, thermodynamics, rotational motion, and electromagnetic induction. These simulations provide opportunities for the user to dynamically manipulate multiple variables to and see the impact in real time. In this exploratory study, we conducted focus group interviews of students who recently completed an introductory algebra-based Physics I course; the simulations were not part of their course. During the interviews, students were engaged in a lesson driven by one of the AR simulations. We then engaged them in a reflection of the experience. They discussed topics such as usability and perceived helpfulness had the simulations been part of the course instruction. Feedback overall was very positive, and students indicated that the additional representations provided in the simulations help them to "see" the concepts they were learning about in class.

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I. INTRODUCTION

Technology can be a very powerful tool for educators. However, we argue that to justify its use, the technological tool should enhance student's experiences and learning over other methods. We thus developed seven simulations utilizing augmented reality (AR). AR takes interactive simulations and overlays them with the real world. For the simulations in this study, users create a cube from a printable net. On each side of the cube is a different picture which the program scans from a mobile device to turn into the different simulations (see Fig. 1).

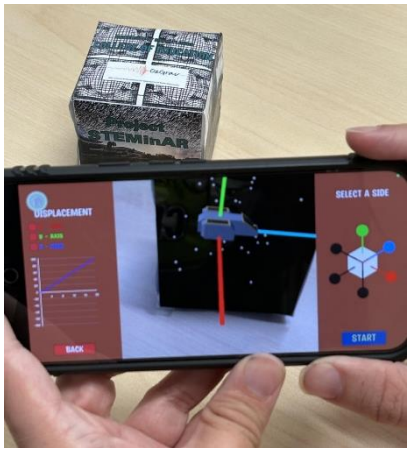

FIG. 1. Printable cube with Force and Motion simulation.

The benefits of AR include increased content retention [1], attention, satisfaction, and student motivation [2]. AR can also increase memory and student engagement [3, 4]. Many of the benefits of learning with AR can be explained by Mayer's "Cognitive Theory of Multimedia Learning" model [5]. Broadly stated, individuals learn better from words and pictures as opposed to just words. AR is interactive and provides pictures, words, and auditory cues. Further, the ability to hold and manipulate the cube, rather than looking at a simulation on a computer screen, provides additional sensory input for students as they learn [6].

There is a great deal of research across all disciplines highlighting the benefits of AR for students [7,8]. We hypothesize, along with others [9,10], that utilizing AR for introductory Physics courses will benefit students. Interactive simulations (e.g., PhET sims) have already been shown to be helpful for students [11]. By combining interactivity with the ability to manipulate variables with both visual and auditory effects, and layering in the tactile element of AR, we have created a tool that maximizes Mayer's theory and may produce positive gains in student learning. Since this can also be used during lecture-based instruction, there is the possibility that large enrollment lecture classes could become more hands-on with little to no cost to the instructors.

This study is an initial one, thus exploratory in nature as we begin to investigate the larger question of using AR to help make large lecture-based classes more interactive. This process is a multi-faceted project with many steps before reaching our final goal. First, we created the desired content and layout of the simulations for Project STEMinAR which was then developed by an external group. Next, members of our team developed accompanying curricula. After the curriculum development, we ran a series of focus groups with students. In the upcoming phases we will be researching effects in the classroom on a broader scale. Ultimately, our goal is to collaborate with other universities for replication.

This paper focuses on the exploratory study to determine usability via student focus groups. Thus, our research question is: what are students' perceptions of the Project STEMinAR augmented reality simulations regarding usability and usefulness as a learning tool?

We piloted the simulations and activities with students who had recently completed an introductory algebra-based Physics course; the simulations were not part of their course. Students were recruited to participate in focus groups centered on a lab-based activity driven [12] by the simulations. Overall, students provided positive feedback on how the simulations helped them understand the content and indicated they wished they would have been able to use them during their class.

II. SIMULATIONS

Project STEMinAR consists of seven simulations: Thermodynamics, Rotational Motion, Optics, Force and Motion, Newton's Cannon, Lenses, and Electromagnets. The research team specifically chose the content based on what is taught in an introductory physics sequence, what content is typically difficult for students, and what would be best visualized in the AR format. Since the research in this paper focuses on three of the simulations, we will only describe those three in depth. A full discussion of the rest can be found at [13]. To use the simulation, you need a controller. This is a downloadable printable that is easily folded to create a cube.

Each of the cube's six sides contains a different image. The program runs on a mobile device (i.e., phone or tablet) and, through the device's camera, reads the images to determine the orientation of the cube. From this, the simulation displays an image over top (and sometimes outside) of the cube. The user can manipulate variables using their device. Figure 1 shows an example of one of the simulations. Notice the Force and Motion simulation has the visual in the center, a graph on the left, and buttons on the

right side of the screen to go to a different screen where the user has the ability to change variables.

A. Force and Motion

Figure 1 shows an image of this simulation. A spaceship is in the center. The right section of the simulation is where users can pick a direction by clicking on the differently colored lines representing *x*-, *y*-, and *z*-axes, (forward/backward, up/down, left/right). This brings up a different screen which allows users to choose initial velocity, force delay (how long before the force is applied), force duration (how long the forces act), and then they can also choose the magnitude of force. Once they run the simulation, users can see the effects of their choices on the movement of the spaceship. When the simulation is running, the left side of the screen allows users the ability to collect real-time data and view graphs of the displacement, velocity, or acceleration versus time.

B. Newton's Cannon

Newton had a thought experiment for orbital motion. He imagined a cannon on top of a very tall mountain and then described what would happen to the cannonball depending on the velocity it exited the cannon. This is a popular simulation found online but those simulations only focus on the cannon ball being on planet Earth. In this simulation (Figure 2), users can choose from multiple planetary bodies. Users can also manipulate the height of the mountain and the speed of the cannonball when fired. By manipulating the cube users can observe the path (sometimes outside of the cube itself) of the cannonball.

FIG. 2. Newton's Cannon simulation.

C. Thermodynamics

Users can simultaneously display both a real-world situation and a molecular model of ice being heated into liquid water and then eventually steam. Users start by inputting the variables of mass, initial temperature, and flow of energy into the system (in kiloJoules per second). The simulation shows the substance and how it changes based on the given conditions (see Fig. 3). Users can also turn to one side of the cube to watch a graph of temperature versus time change in real time to the simulation.

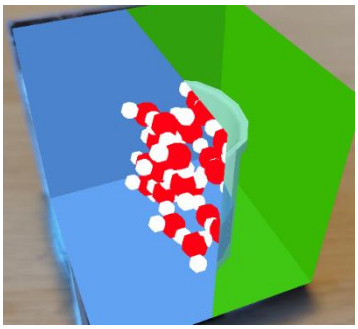

FIG. 3. Thermodynamics simulation.

III. METHODS

A. Sample and Setting

We conducted this study at large metropolitan university. We recruited focus group participants who were students enrolled in an introductory algebra-based Physics I course. The course itself was a large lecture-based course which was in-person and supplemented with online resources.

The 11 participating students did not use any simulations or AR in their class. They were compensated with a $40 Amazon gift card for the two hour session.

B. Intervention and Data Collection

We conducted four in-person sessions with 1-4 participants in each interview; these were video recorded and transcribed. Each interview focused on one of three simulations: Force and Motion, Newton's Cannon, or Thermodynamics.

Data sources included interview transcripts and pre- and post-surveys. The surveys, administered online, gathered information about students' physics background, their content knowledge about the specific simulation topic, and their confidence level with the content. The post-survey included additional items that asked students to reflect on their experience with the simulation, activity, and content.

When the students arrived at their interview, they completed the pre-survey individually. Then, we asked the group questions regarding the content around the specific simulations they were going to use during that interview. Next, the lead author engaged students in an inquiry-based lab activity developed from the Investigative Science Learning Environment framework [14]. Each simulation was integral to the associated activity and can be found on the project website [13]. The goals of these labs are to have

students manipulate variables to develop their own model of understanding, which could then later be tested. The students completed one section of the activity at a time and then discussed it as a group. The interviewers did not correct any student statements during the activity or interview; we were there to help guide them through the activity and answered procedural questions when needed. However, at the end of the session, the lead author answered lingering questions about the content, made clarifying statements, and ensured that students did not leave with any misconceptions. Within 48 hours after completion of the focus group session, students were asked via e-mail to complete the post-survey.

C. Data Analysis

The inductive analysis process entails researchers reading through the data by allowing codes to emerge in this process [15]. We followed Bingham and Witkowsky's [16] outline of inductive practices: "(1) Make meaning from the data, (2) Develop codes, themes, and findings, (3) Identify representative data to support findings, and then finally (4) Explain findings using theory and literature." Staying true to the goals of this study, we were attentive to student engagement, learning, interest, and application usability. Through these lenses, we began to review the videos and transcripts inductively to allow for codes to emerge from the participants' voices and actions.

To begin the meaning-making process, three of the authors reviewed the transcripts and videos holistically. This provided an overall understanding of the focus group activity. After examining the video and transcript, this sub-team met to discuss the different ideas they interpreted. They began looking at specific quotes they had all highlighted as important and discussed why they felt it was important. From these conversations, they began to form different codes that encompassed their interpretations of the interviews. For example, "this is really cool" refers to the participant's interest in the cube's capabilities, thus, they coded it as interest. As they went through these codes, they began to see some commonalities and grouped the codes into categories. Each researcher applied these codes to the same video, then they met again to discuss their interpretations. They added new codes as needed and revised existing ones to align with the interpretations of each researcher. They applied the new codes to the next video and repeated the process of revising existing codes. Next, one author applied the codes to the second focus group, and the other two reviewed the coding and added comments to agree or disagree with the application of codes by the first author.

After coding the completed transcript for each focus group, the researchers met and began discussing patterns. These patterns became our themes presented in the findings.

IV. FINDINGS

A. Focus Groups

The focus groups had both general themes that emerged across all groups, as well as individual themes specific to a particular session. The first general theme students reported is that **the simulations helped them build connections with the content**. The visuals in the simulations and the ability to manipulate variables and see the immediate result supported students' understanding. One student stated, *"I feel like sometimes even if we use visuals in some lessons, it's hard to connect it with concepts like velocity and acceleration. So, you being able to manipulate that instead of just like pushing something in real life, like able to change the values of multiple things at once, really help like see what is proportional to other things."* This type of comment is found in all of the focus groups. A participant in a different group with a different simulation stated: *"my knowledge of it [the content] would be way more [sic] better. Because like, like I said, you get to change the values. So if I have any questions, which I did, like, "how does kJs affect it? How does temperature affect it? How does the weight of it affect it?" Like, if my teacher had this on hand, they could have easily just plugged it in and then showed me in real time.*" This allowed students to make observations and develop patterns from the simulation.

Students also combined their work on the simulation with their lived experiences and were able to draw their own conclusions regarding content and what they had seen before. *"I kind of see, like, because I'm trying, this kind of reminds me of like when you push ice."*

Another aspect of the simulations that the students talked about often were the additional representations that dynamically change in real time. Multiple, linked representations are a defining feature of the simulations and have already been shown to support student success [17]. In addition to the pictures and visuals, some of the simulations make use of graphical representations. One student stated, "*I think it's cool to see the graphs in real time [and] what happens because I was always confused with that, like what was happening with acceleration. So now seeing that, it helped [me] understand what we were doing."* This statement was not confined to one content area. One participant had difficulty with thermodynamics, but upon working with the simulation: "*it was messing with me. I was like, wait. But then once I started to look, look back at, at the graph itself, it shows you just exactly what you're looking for.*" In some cases, a participant commented on how they could not understand something in class but was able to understand with the help of the simulations: *"I was kind of like lost before and I feel like now that I have like a better basic understanding, it's like, okay, now I have this pretty solid of how this is proportionate to this. So, then it's like*

taking that a step further when it applies to other like situations and models, I can take it I can feel confident taking it a step further and asking deeper questions."

Participants were also able to address their incorrect beliefs about the content. Weightlessness is a challenge to many students; *"I always thought that the reason why you're weightless is because, oh, there's no gravity, but it's like it is that, but there's like more to it."* As students worked with the simulations, it was evident that they were thinking and trying to reconcile their understanding of the content with the help of the simulation: *"I was thinking about like the centripetal acceleration and I don't think it makes sense because, the gravity's this way and then they're going this way."*

The participants' statements also led to a second major theme across the groups, which focused on discourse itself. **The simulation provided a common reference for the students to have conversations with one another**, whether it was a physics term they could not explain or share what they did with one another and supporting one another. They felt comfortable talking because of the shared experience with the simulation: *"Lots of people would feel embarrassed articulating that, so this [the simulation] would definitely be good for answering that question."*

B. Surveys

The students gave a great deal of positive feedback about the simulation and their understanding of the content during the interviews; however, we wanted to gather more information via a pre- and post-survey. All the students self-reported an increase in their understanding of the material, regardless of the content: *"I shared [with others] that I finally understood the idea of velocity, acceleration, and forces and that the concepts finally 'clicked'."* Another stated, *"Now I am able to attach certain images in my head that correlate to each law which I believe has improved my understanding."* A student who initially ranked their understanding at a 1 (on a 5-point scale, 1 being the lowest), then after the intervention, at a 4, stated at first that, "*physics is a real tough concept for me to grasp."* On the post-survey, the same student stated, "*after completing the simulation and the lab, the application of gravitational force makes more sense*." Some of the participants (7 of the 11) discussed how they shared their experience in the focus group with someone else: *"I shared it with my partner who would want to try out the app or other models the app provides. Stressing the fact that the cube helps the visual of motion in all directions.*"

Since the students were participating in the focus groups for two hours or less, we were not expecting significant gains in content understanding. This is an area for future studies, but it is clear the simulations have potential to be a helpful tool for instructors. Students self-reported an increase in their confidence with the content. When we asked to rank themselves on their confidence with Newton's laws (1 being low and 5 being extremely confident), scores rose from 3.33 to 4.14. That said, some incorrect ideas still remained. For example, we asked students, if an object was moving to the right, what do you know about velocity, acceleration, and force? Some responses still indicated that acceleration or force was to the right; however, a few students did change their response from the pre-survey that acceleration is to the right to, on the post-survey, not being able to know anything about the acceleration of the object.

V. DISCUSSION AND FUTURE WORK

Overall, the students reported not only enjoyed using the simulations, but it helped them in multiple stages of learning. They stated how they were able to visualize the content better than what was accomplished during the classroom instruction. They were able to use the features of the simulations to investigate cause and effect relationships which helped them create their own models. Students were also able to use their common experiences with the simulation to lead and generate discussions with other students, both to support their own understanding and that of their peers. Ultimately, even after a short amount of time, we observed students were able to verbally explain difficult concepts like weightless in space correctly by sharing what they learned and experienced with Project STEMinAR simulations.

One of the biggest takeaways is how the simulations helped the students in multiple ways. By adding the sensation of touch for them to hold and manipulate the simulations while at the same time being able to change the variables to see the results, students reported that they were able to use the simulations to help them understand the concepts.

As these findings are exploratory in nature since they focus on student's beliefs about the simulations, future work will involve studies on learning gains. We will be analyzing differences in how students respond to assessment questions in large lecture-based courses, labs, and virtual assignments.

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[1] E. Goff, K. Mulvey, M. Irvin, and A. Hartstone-Rose, Applications of augmented reality in informal science learning sites: a review, in *Journal of Science Education and Technology*, **27** (5), (2018), pp. 433-447.

[2] G. Ramya and P. Madhumathi, Augmented reality for English language teaching and learning. *Language in India*, **17**, (2017), pp. 352-360.

[3] M. Maas and J. Hughes, Virtual, augmented and mixed reality in K-12 education: A review of the literature. *Technology, Pedagogy, and Education.* **29** (2), (2020), pp. 231-249.

[4] M. Akçayır and G. Akçayır, Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, **20,** (2017), pp. 1-11.

[5] E. Mayer, Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*, **41**, 1, (2005), pp. 31-48.

[6] R. Mayer and R. Moreno, A cognitive theory of multimedia learning: Implications for design principles." *Journal of educational psychology*, **91**, 2, (1998), pp. 358-368.

[7] M. Antonioli, C. Blake, and K. Sparks, Augmented reality in education. *The Journal of Technology Studies*, (2014), pp. 96-107

[8] M. Bower, C. Howe, N. McRedie, A. Robinson, and D. Grover, Augmented Reality in education–cases, places and potentials. *Educational Media International*, **51,** 1, (2014), pp. 1-15.

[9] M. McColgan, G. Hassel, N. Stagnitti, J. Morphew, and R. Lindell, Augmented Reality to Scaffold 2D Representations of 3D Models in Magnetism, 2023 *PERC Proceedings* [Sacramento, CA, July 19-20, 2023], edited by D. L. Jones, Q. X. Ryan, and A. Pawl, doi:10.1119/perc.2023.pr.McColgan.

[10] M. Strzys, M. Thees, S. Kapp, and J. Kuhn, Smartglasses in STEM laboratory courses – the augmented thermal flux experiment, 2018 PERC Proceedings [Washington, DC, August 1-2, 2018], edited by A. Traxler, Y. Cao, and S. Wolf, doi:10.1119/perc.2018.pr.Strzys.

[11] C. Wieman, K. Perkins, and W. Adams, Oersted Medal Lecture 2007: Interactive simulations for teaching physics: What works, what doesn't, and why. *American Journal of Physics*, **76,** 4, (2008), pp. 393-399.

[12] K. Findley, I. Whitacre, and K. Hensberry, Integrating interactive simulations into the classroom: Supplementing, enhancing, or driving? In E. Galindo & J. Newton (Eds.), *Proceedings of the 39th annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education*, (2017), pp. 1297-1304.

[13] https://www.usf.edu/education/faculty/rosengrant-virtual-stem-laboratory/augmented-virtual-reality-projects/ Retrieved 08/12/2025

[14] E. Etkina, A. Karelina, M. Ruibal-Villasenor, D. Rosengrant, R. Jordan, and C. Hmelo-Silver, Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories. *The Journal of the Learning Sciences*, 19(1), (2010), pp. 54-98.

[15] M. Miles, M. Huberman, and J. Saldaña, *Qualitative data analysis: A methods sourcebook*. 3rd. (2014).

[16] A. Bingham and P. Witkowsky, Deductive and inductive approaches to qualitative data analysis. *Analyzing and interpreting qualitative data: After the interview*, **1,** (2021), pp. 133-146.

[17] D. Rosengrant, A. Van Heuvelen, A., and E. Etkina, E. (2006, February). Case study: Students' use of multiple representations in problem solving. In *AIP Conference Proceedings*, **818**, 1, (2006), pp. 49-52.