Original Article

e-learning and digital media

E-Learning and Digital Media
2024, Vol. 0(0) 1–21

DOI: 10.1177/20427530241276153
journals.sagepub.com/home/ldm
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Cloud-based STEM learning: Using an online simulation to teach renewable resources management in a remote learning classroom during the COVID-19 pandemic

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Abstract
During the abrupt and unplanned transition to remote online learning formats due to the COVID-19 outbreak, educators have had to adopt new teaching methods. For instance, online simulations tailored to specific curriculum topics emerged, allowing students to apply their knowledge creatively, with potentially positive effects on engagement and learning efficacy. Here, we examine the implementation of the "Save the World" simulation, created by Wonderville.org, in a high school Advanced Placement Environmental Science classroom in a remote online learning setting. In this module, students determine the most viable renewable energy generation option for given environments. Based on student and teacher feedback, the simulation effectively delivers educational material and promotes student engagement, demonstrating that online simulations can serve as a viable tool to enhance environmental science education and remote learning.

Keywords
Advanced placement environmental science (AP environmental science), educational technology, online simulation, K-12 STEM, remote online learning

Introduction

COVID-19 and the transition to remote learning

On March 11th, 2020, the World Health Organization (WHO) declared COVID-19 a global pandemic (Ghebreyesus, 2020), compelling school districts across the United States to consider closures to prevent the possibility of school-wide outbreaks (Hammerstein et al., 2021). The next day, districts across the nation announced that their schools would switch to remote online learning until it was safe to gather in person (Hanley et al., 2020). Remote online learning, thus, became the new standard for an entire generation of students. Even as students have started returning to in-person classroom settings, online remote instruction has remained a mainstay in education whose impact on academic development has been documented by a multitude of studies (Johnson et al., 2023; Middleton, 2020; Wharton-Beck et al., 2024; Winter et al., 2021).

Online learning (also referred to as virtual learning) is a model of education where students engage in their lessons via the internet, using a personal device. While it is possible to adopt an online learning model in face-to-face settings, online models have typically supported remote (also called distance) learning, where the students reside in a separate location from the teacher (Summers et al., 2005). Amongst a gauntlet of other challenges, student engagement has been recognized as one of the most prominent hurdles in contemporary education. In fact, chronic boredom resulting from disengagement in the classroom is the leading impetus driving premature student drop-out, spurring research into identifying and developing tools to not only improve grades, but obtain and retain student engagement (Rothkrantz, 2017; Willms et al., 2009). Extensive research has been conducted on the use of simulations and games for learning as a method of engaging and motivating students (Chelberg et al., 2008). This is particularly important in the case of remote learning, when perceived levels of engagement (i.e. student engagement as judged by an external observer such as an instructor) can drastically differ from actual levels. Removing physical presences and introducing a plethora of off-screen distractions in these new remote online learning environments has made it exceedingly difficult to gauge mental presence (Blasiman et al., 2018). Although perceived levels of engagement (i.e. student engagement as judged by an external observer such as an instructor) can drastically differ from actual levels, many instructors still rely on visual cues to adapt their teaching behavior, making it a metric of interest (Ainley et al., 2002). Evidently, maintaining student-teacher interaction in a remote online setting requires substantial efforts to restructure lessons and teaching styles to keep students interested, engaged, and willing to communicate (Velasquez et al., 2013). Engaging activities, such as online simulations, may therefore play a valuable role in improving student engagement with the learning material while simultaneously enabling teachers to remain receptive to the needs of their students.

Integration of digital teaching resources into STEM education

Science, Technology, Engineering, and Mathematics (STEM) education can be difficult to communicate, even in an in-person setting, because it relies on foundational knowledge from the students and requires them to think on scales they cannot experience in their everyday lives, from the nanoscopic (e.g. Chemistry) to the macroscopic (e.g. Environmental sciences) scale. Even before the transition to remote learning, in-person STEM education was frequently supplemented with dynamic computational models or other simulations that offer perspectives that may be difficult to directly visualize; however, a physical component was often important for demonstrating to students the real-world applicability of these models (Jihad et al., 2018; Jones et al., 2019; Kim et al., 2014; Lewis et al., 2012; Lorenzini et al., 2011; Monkovic et al., 2022). With the loss of the in-person component, online STEM education demands a more dynamic, hands-on, intensive teaching style to stay effective in a remote learning environment.

Indeed, both teachers and students reported frustration with the difficulty of engaging in virtual lessons. However, embracing the unique capabilities of online education platforms, instead of outright rejecting them, could alleviate these frustrations. A bevy of studies have examined the advantages of online classes and remote education (Camargo et al., 2020; Dhawan, 2020; Nambiar, 2020). An online setting offers an opportunity to connect students and teachers to specialized resources and improve the online learning experience for all parties (Barbour et al., 2013). Cloud-based learning refers to digital hardware and software computing resources to generate a virtual learning space on a network, typically the internet. These virtual learning environments eliminate the need for in person meetings and downloading memory-dense software, since cloud-based resources are not tied to a specific local device. Examples of cloud-based educational tools currently employed by teachers include: (1) Zoom Polls which allow participants to vote on certain options and display the distribution of responses (McCarthy, 2022); (2) Google Forms which can deploy a variety of question formats such as short answer, checkboxes, and dropdown (Nguyen et al., 2018); and (3) Kahoot!, a competitive multiple-choice game where students are awarded points based on the speed and accuracy of their answers (Chaiyo and Nokham, 2017; Jones et al., 2019). Simulations refer to a specific subsection of cloud-based resources that immerse students in a fictional scenario where they can apply lesson topics. This allows students to test different ideas and understand which approaches fail or succeed at their own pace. Often, simulations are presented in a gamified manner with interactive visualizations that students can experience and engage with on their personal devices (Polat et al., 2013). While online simulations, as well as role-playing simulations performed in-person (Wieman et al., 2008), have been used occasionally in classrooms, these tools have recently gained renewed importance in light of COVID-19 school closures and the increasing presence of remote education options for K-12 learners (Galeote and Hamari, 2021; Watson et al., 2013). Relatively fewer studies probe the use of cloud-based software as supplemental learning resources rather than a vehicle for educational delivery (e.g. Zoom).

PhET is an expansive suite of free online simulation tools designed with the goals of encouraging student exploration and independent engagement, enjoying widespread acceptance as supplements to traditional education (Astutik and Prahani, 2018; Wieman et al., 2008). However, PhET currently lacks a strong offering in environmental conservation and sustainability sciences, being mostly focused on physics and chemistry of natural processes. Inspired by the success of PhET, we aimed to determine whether a similar exploration-focused simulation could be effective in helping students understand the factors involved in designing infrastructure for environmental conservation. "Save the World" is an understudied stand-alone web simulation that is suitable for engaging Advanced Placement Environmental Science (APES) students in this topic. This study focuses particularly on the AP level, where college-level performance is demanded of high school students, and where applied topics become increasingly disparate. It is also at this level that STEM education is associated with social mobility and societal value as secondary school students transition into their college careers (Xie et al., 2015). Indeed, AP education represents a critical period for prospective scientists and engineers, where they gain fundamental knowledge and physical intuition for research and technical application (Kolluri, 2018).

Study objective

The objective of this research is to investigate how an interactive, cloud-based simulation called "Save the World" can help APES students articulate various mechanisms available for harnessing renewable resources while facilitating engagement with the material in a remote learning context.

Design, methodology and approach

Collaboration with the urban assembly institute of math and science for young women

Located in Brooklyn, New York, the Urban Assembly Institute of Math and Science for Young Women (UAI) is a public school focused on fostering interest in STEM in young women of underrepresented communities (U.S. News Rankings 2024). 87% of the students come from minority backgrounds, with 78.1% of students identifying as ethnicities currently underrepresented in STEM (e.g. Black, Hispanic, American Indian/Alaska Native) (Grieco et al., 2023). Furthermore, 85% are economically disadvantaged. UAI therefore represents an institution where improvements in STEM education may translate to increased diversity in the STEM workforce.

APES curriculum at UAI contains a "Lab and Field Investigations" component that is traditionally performed by students enrolled in the course in an in-person congregated lab setting (College Board 2020). During the COVID-19 transition, students enrolled at UAI were required to obtain their own internet-enabled device, offering an opportunity for our team to deploy cloud-based online simulations for feedback and formative assessment. Our team selected the online "Save the World" simulation because it strikes a good balance between instructional and interactive elements. Students are presented with a region and design a system from a set of renewable energy resources. They are allowed creative freedom with regard to which resources they wish to invest in a particular environment and are provided immediate feedback on the effectiveness of their choices. If students were unable to meet the required energy threshold for the region with their approach, they are prompted to reflect and try a different approach, providing instruction but encouraging innovation and further interaction. Additionally, we felt the simulation's title and graphics adequately captured the global importance of ecodiversity and energy sustainability.

Implementation of the "Save the World" online simulation

Following a short informational preface about the activity, the web address for "Save the World" was distributed to students by their instructor. Then, UAI students independently engaged with the simulation in a synchronous Zoom session for the remainder of the fifty-five-minute class period. In total, students spent around 40 minutes interacting with the simulation.

"Save the World" tasks students with choosing ideal alternatives to fossil fuels for seven regions with distinct geographic features (Figure 1(a)). When the simulation is first launched, it provides a short instructional video with narrated animations to give students a basic understanding of how electricity is generated, and how alternative energy sources can substitute the functions of burning oil or coal in a steam engine. Five different methods of alternative energy generation are briefly introduced (Figure 1(b)).

Each region lends itself to different methods of energy generation. To illustrate, the Canadian region is depicted as an ice shelf bordering the ocean where tidal power would be the ideal energy source, whereas the USA region is a landlocked flatland where solar and wind power would be appropriate, and Norway (Figure 1(c)) utilizes hydropower in a running fjord. Students drag the icons representing different methods of harnessing energy from the heads-up display (HUD) to bulls-eye markers on the graphical user interface (GUI) representing the landscape of the region (Figure 1(c)).

Each bullseye marker represents an available site for an alternative energy power plant. Immediately after placement, students are given a score between +0 kw/h and +25 kw/h based on the

Figure 1. Screenshots from "Save the World" simulation from wonderville.org (Weber, 2021). (a) Start page depicting seven regions in the game: "Canada," "USA," "France," "India," "New Zealand," "Japan," and "Norway". (b) Alternative energy converter options accompanied by representative icons: "Tidal," "Wind," "Solar," "Geothermal," and "Hydroelectrical". (c) Player's Graphical User Interface (GUI) view with Heads Up Display (HUD) at the bottom. (d) End of activity screen.

Student Pre-Survey (S_0)

S_0Q1. On a scale of 1 – 10 (1 being not familiar and 10 being very familiar), how familiar are you with the term "renewable resources"?
S_0Q2. On a scale of 1 – 10 (1 being not well and 10 being very well), how well do you think you could explain the idea of "renewable resources" to your friends?
S_0Q3. On a scale of 1 – 10 (1 being not familiar and 10 being very familiar), how familiar are you with the various types of renewable resources?
S_0Q4. On a scale of 1 – 10 (1 being not confident and 10 being very confident), how confident are you in explaining the various types of renewable resources to your friends?
S_0Q5. On a scale of 1 - 10 (1 being do not enjoy at all and 10 being really enjoy) how much do you enjoy learning various topics in person?
S_0Q6. On a scale of 1 – 10 (1 being do not enjoy at all and 10 being really enjoy), how much do you enjoy learning various topics remotely?
S_0Q7. On a scale of 1 – 10 (1 being not difficult at all and 10 being very difficult), how difficult is learning topics in person?
S_0Q8. On a scale of 1 – 10 (1 being not difficult at all and 10 being very difficult), how difficult is learning topics remotely?

Figure 2. Student pre-survey questions (S_0Q1–Q8) distributed to students through Google Forms.

Student Post-Survey (S_f)

S_fQ1. On a scale of 1 – 10 (1 being not familiar and 10 being very familiar), how familiar are you with the various types of renewable resources after today's simulation?
S_fQ2. On a scale of 1 – 10 (1 being not well and 10 very well), how well do you think you could explain the idea of "renewable resources" to your friends after today's simulation?
S_fQ3. On a scale of 1 – 10 (1 being not confident and 10 being very confident), how confident are you with explaining the various types of renewable resources to your friends after today's simulation?
S_fQ4. On a scale of 1 – 10 (1 being did not enjoy at all and 10 being really enjoyed), how much did you enjoy learning about renewable resources with today's simulation?
S_fQ5. On a scale of 1 – 10 (1 being not effective at all and 10 being very effective), how effective is the simulation in helping you understand various renewable resources?
S_fQ6. On a scale of 1 – 10 (1 being not easy at all and 10 being very easy), how easy was it to use the simulation?
S_fQ7. On a scale of 1 – 10 (1 being not likely and 10 being very likely), how likely are you to recommend this simulation for future AP Environmental classes?
S_fQ8. On a scale of 1 – 10 (1 being not likely and 10 being very likely), how likely are you to recommend this style of teaching in your future classes?
S_fQ9. What do you like about the simulation?
S_fQ10. Is there anything you wish we could include in the simulation to improve it?
S_fQ11. Additional Comments and Concerns

Figure 3. Student post-survey questions (S_fQ1–Q11) distributed to students through Google Forms.

appropriateness of their selection. A region is considered complete when a net threshold of 100 kw/h is achieved. Following the completion of each region, the simulation plays another instructional video with detailed schematic flow diagrams showing how a particular type of renewable energy resource utilized in that region generates electricity (Figure 1(d)).

Teacher's Survey (T_f)

T_fQ1. On a scale of 1 – 10 (1 being not engaged at all and 10 being extremely engaged), how engaged did you feel the students were in remote learning?
T_fQ2. Please describe how you assess engagement:
T_fQ3. On a scale of 1 – 10 (1 being not well at all and 10 being very well), how well do you feel the students understand the various types of renewable resources?
T_fQ4. On a scale of 1 – 10 (1 being not engaged at all and 10 being extremely engaged), how engaged did you feel the students were in the lesson with the simulation?
T_fQ5. Please describe how you assess engagement and whether it is the same as that before implementation:
T_fQ6. On a scale of 1 – 10 (1 being not at all and 10 being very well), how well do you feel the students understand the various types of renewable resources with the simulations?
T_fQ7. On a scale of 1 – 10 (1 being not difficult at all and 10 being very difficult), how difficult is it to introduce the simulations to the students?
T_fQ8. What was your favorite part about the simulations?
T_fQ9. On a scale of 1 – 10 (1 being not likely and 10 being very likely), how likely are you to recommend these simulations to another teacher?
T_fQ10. On a scale of 1 – 10 (1 being not likely and 10 being very likely), how likely are you to use this style of teaching again in the future?
T_fQ11. How would you improve the simulations and the contents?
T_fQ12. Additional Comments and Concerns:

Figure 4. Teacher post-survey questions (T_fQ1–Q12) distributed to UAI instructors through Google Forms.

Student and teacher surveys to gauge the level of engagement

Abiding by guidelines set by New York's Institutional Review Board (See **IRB Statement**) and separately agreed upon collaboration terms established with UAI, our team collected anonymized, self-reported data from both students and teachers in the form of questionnaires distributed as electronic Google Forms (Figures 2–4).

The student pre-survey had eight questions in total (Figure 2). **S_0Q1–Q4** gauged students' initial familiarity with the topic presented by the online simulation—renewable energy resources—to determine if engaging with the material via the online simulation would improve their understanding. Students were tasked with rating, on a Likert scale of one to ten, their background knowledge of the term "Renewable Resources", their understanding of the various types of renewable energy resources used around the world, and their ability to explain both concepts to their peers. **S_0Q5–Q9** asked students to rate their enjoyment and the difficulty they experienced with different learning modes (in-person vs. online). Enjoyment and difficulty were deliberately delineated to avoid conflating the two as students may enjoy a challenging educational experience. These queries evaluated students' perceived differences between the two modes.

The student post-survey had ten questions in total (Figure 3). Utilizing the same Likert rating system as the pre-survey, **S_fQ1–Q3** mirrored **S_0Q2–Q4** of the pre-survey, asking the students to account for the material they had learned through the online simulation. **S_fQ4–Q6** probed students' experiences with the simulation, asking them to rate how much they enjoyed it, how helpful they believed it was in aiding their understanding, and how easy it was to use. These questions would determine the viability of a teaching tool that relied on students independently navigating an unfamiliar online resource. **S_fQ7–Q8** extended the previous inquiry by asking students if they would recommend this specific simulation and online simulations in general as tools for future APES teachers. This would help determine if introducing advanced environmental science concepts through online simulations would be beneficial and whether students would accept online simulations as a viable learning option. The final questions of the survey **S_fQ9–Q11** solicited written feedback on students' experiences with the simulation, including what they liked and what could be improved. These responses would identify specific areas where online simulations are either beneficial or problematic in an APES classroom.

A single post-activity teacher survey containing 11 questions was distributed to UAI instructors following the implementation of "Save the World" (Figure 4). The teacher's survey provided an educator's perspective on the use of online simulations, as well as an assessment of student understanding and engagement that was not reliant on students' self-awareness and reflection.

Additionally, to gauge the baseline class experience and perceived level of student engagement, our team was invited to attend virtual sit-in sessions, observe, and note differences in remote class sessions before and after the deployment of "Save the World" (Figure S1).

Statistical analysis of quantitative survey results

Upon completion, survey results were aggregated, analyzed, and charted in Google Sheets. Although the content of the simulation was delivered to 68 UAI students across two class sections, only 36 students completed both the pre and post-activity surveys yielding a paired sample size of $n = 36$. Statistics were computed for each numerical response and reported as a mean ± standard error ($\bar{x} \pm \sigma/\sqrt{n}$). A Student's paired t test was performed on the data to calculate p-values and assess statistical significance ($^*p < .05$, $^{**}p < .005$, $^{***}p < .0005$). Responses were also compiled into a histogram format to observe the shape and spread of the distribution. Using standard significance levels (i.e. $\alpha = 0.05$ and $\beta = 0.20$), the study effect size (i.e. Cohen's d) and power were calculated post hoc as:

$$d = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}} \tag{1}$$

$$Power = 1 - \Phi\left\{-1.96 + \frac{|\bar{x}_2 - \bar{x}_1|}{\sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}}}\right\} \tag{2}$$

where $\bar{x}_a$ is the sample mean and σ_a is the standard deviation. Φ corresponds to a function converting a critical Z-value to power.

Qualitative sentiment analysis of open-answer responses

S_fQ9–Q11 on the student post-survey and **T_fQ2, T_fQ5, T_fQ8, and T_fQ11** on the Teacher's survey were manually organized and analyzed qualitatively. Commonalities in student responses were identified, whereas responses to the teacher survey were interpreted to gain further insight into the instructor's perspective of the simulation and simulation-based teaching styles. Vague responses (e.g. "not sure" or "everything") were not considered.

Results and discussion

Comparison to control: Observations of a typical remote learning session

A typical in-person lesson is teacher-centric: it involves one teacher at the front of the class imparting the material to students who follow along. Class sessions are held either (1) synchronously, where the students are present on a conference call at the same time as an instructor, or (2) asynchronously, where students are given material to guide themselves through on their own time. Typically, synchronous remote lessons given over an online platform use a similar technique, with a teacher "screen sharing": having every student see the same thing that the teacher is seeing on their personal devices, and following along, as if they were watching a teacher at the front of a classroom. Comparatively, asynchronous learning lends itself to a more student-centric style; the lack of physical presence with their teacher requires them to work more independently. Students create their own structure and discipline themselves; however, when removed from the structured classroom environment, many students have difficulties staying engaged as there are more opportunities for the student to multitask undetected, limiting their focus and adversely reflecting their recall ability of the material (Blasiman et al., 2018).

On March 9th of 2021, our team conducted an observation of two synchronous online learning sessions via Zoom with UAI APES students (Figure S1). One session used Peardeck (Mache et al., 2017) and Jamboard (Khoiriyah et al., 2022), two cloud-based learning tools that solicit and display student responses to pre-written prompts, to facilitate the sharing of ideas and student-to-student inspiration, while the other session did not use these resources. Unlike an in-person hand raise, an unmuted speaker on a video call, or a chat message with an attached username, where students must identify themselves as the respondent, answers given on these cloud-based resources are anonymized. 50–80% of students in the session utilizing Peardeck and Jamboard responded to question prompts, whereas only 4%–20% of students in the session conducted without these anonymity-promoting tools responded to the instructor's verbally administered prompts (Figure S1). Therefore, anonymizing responses through cloud-based resources was anecdotally observed to augment participation when the unique advantages of online learning were embraced.

This element of anonymity and independent learning is similarly present with self-directed activities like "Save the World," as instructors cannot track the student's progress or specific answers on a third-party website. In this manner, some of the benefits of asynchronous learning are combined with those of synchronous instruction. Students are given more freedom to experiment, while the instructor maintains control. It shifts the burden of assessment, somewhat, onto the student and encourages self-reflection. This self-motivated participation positively contributes to the student's learning (Latham and Hill, 2014). However, some students who are motivated by introjected regulation, or the feeling of doing tasks due to perceived obligation rather than enjoyment, may still benefit from the external encouragement of a non-anonymous in-person learning space (Polat et al., 2013).

Effectiveness of the web-based simulation in boosting student self-efficacy

In this new remote online learning environment, traditional letter-based grades were deemed ill-suited to evaluate student performance and schools initially opted to switch to a "credit-no-credit" system (Hanley et al., 2020). The COVID-19 pandemic, however, instigated an unprecedented combination of emotional distress (Hawrilenko et al., 2021), financial hardship (Andrew et al., 2020), and dwindling support (Grewenig et al., 2021) that moved schools to develop "grading with compassion" proposals about a week later (Hanley et al., 2020).

Compassionate grading and teaching begin with the notion that faculty must elevate their awareness of student struggles and suffering, especially in extenuating circumstances, followed by an expression of sympathetic concern and a desire to provide relief (White and Ruth-Sahd, 2020). Marked by flexible pedagogy, effective communication, and receptiveness to adopting new technological tools, compassionate approaches to education were critical to maintain student well-being and success during the pandemic (Gelles et al., 2020). Evidently, modifications to traditional philosophies and teaching methods are necessary to adapt to the online learning model challenges that COVID-19 and remote learning brought. Students could not be expected to perform at the same levels as they had pre-pandemic.

The "Save the World" simulation introduced both the importance of renewable energy resources in creating a sustainable future and the various types of energy sources that could act as an alternative to fossil fuels. The survey questions were grouped based on the students' self-rated understanding of those two concepts. The students were asked to consider if they could explain the ideas presented to them in their own words to their peers. $\mathbf{S_0Q2}$ and $\mathbf{S_fQ2}$ established a baseline and gauged whether the simulation helped or hindered the students' ability to articulate the idea of renewable resources. Responses to $\mathbf{S_0Q2}$ averaged at 5.39 ± 0.40, while responses to $\mathbf{S_fQ2}$ averaged at 7.28 ± 0.37, representing a statistically significant ($p = .0009$) difference of large sample effect size 0.8176 and 99.7% power (Figure 5(a)).

Figure 5(b) and (c) display the distribution of student responses, with 50% of respondents rating their ability to explain renewable resources at 5 or below before the simulation, and only 11% after. This shift in distribution to the upper range of 6 or above indicates the simulation aided in empowering the students to articulate the idea of renewable resources in their own language.

The students were also asked to self-rate their ability to explain the various types of renewable energy resources (Tidal, Wind, Solar, Geothermal, and Hydroelectric) before and after the simulation in $\mathbf{S_0Q4}$ and $\mathbf{S_fQ3}$. $\mathbf{S_0Q4}$ had an average response of 4.78 ± 0.46, and $\mathbf{S_fQ3}$ had an average response of 7.06 ± 0.37, representing a statistically significant ($p = .0002$) difference with a large

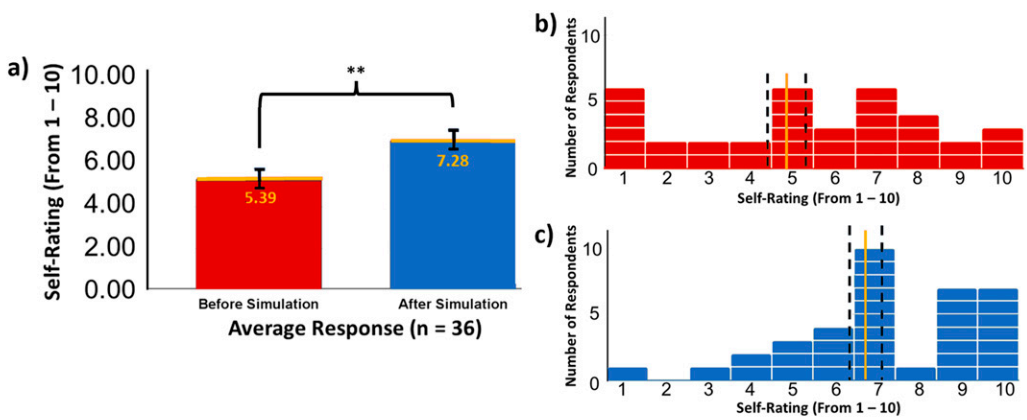

Figure 5. (a) Summary of student self-rated ability to explain "Renewable Resources" before and after simulation implementation. (b) Distribution of pre-survey responses to $\mathbf{S_0Q2}$ (red). (c) Distribution of post-survey responses to $\mathbf{S_fQ2}$ (blue). Average rating (yellow solid lines) and standard error (black dotted lines) are depicted on each histogram. ** denotes $p < .05$.

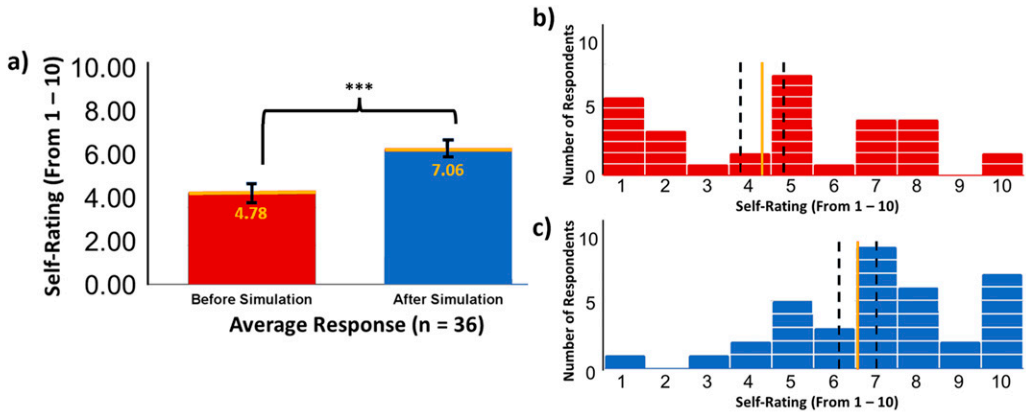

Figure 6. (a) Summary of student self-rated ability to explain "Various Types of Renewable Resources" before and after simulation implementation. (b) Distribution of pre-survey responses to **S_0Q4** (red). (c) Distribution of post-survey responses to **S_fQ3** (blue). Average rating (yellow solid lines) and standard error (black dotted lines) are depicted on each histogram. *** denotes $p < .0005$.

sample effect size 0.9103 and 100% power (Figure 6(a)). Figure 6(b) shows the distribution of responses to **S_0Q4**. 64% of respondents rated their ability to explain the various types of renewable energy resources at 5 or below. Figure 6(c) shows the distribution of responses to **S_fQ3**. 75% of respondents rated their ability at 6 or above, indicating an increase in students' confidence levels in explaining various types of renewable resources, based on the prompted self-assessment in the survey question ("On a scale of 1-10, how confident are you with explaining the various types of renewable resources?") both before and after the simulation. Interestingly, students rated their ability to explain specific diverse types of renewable energy resources (Figure 6(b)) lower than they rated their ability to explain the concept of renewable energy resources (Figure 5(b)). Students may have more hesitation explaining more technical concepts, such as the scientific principles behind each energy source, as opposed to explaining a higher-level concept such as "renewable resources."

Self-efficacy, as evaluated by these questions, plays a pivotal role in motivating effort and dedication to specific tasks, as individuals are more inclined to invest in tasks they believe they can succeed in (Schunk and DiBenedetto, 2016). Moreover, it has also been recognized as a significant factor influencing students' vocational aspirations and their pursuit of more complex tasks (Ponton et al., 2001; Schunk and DiBenedetto, 2016). The positive increase in student self-efficacy echoes similar results from other pre- to post-instruction surveys (Clauss and Geedey, 2010; Conderman and Hedin, 2012). By demonstrating specific principles using engaging graphics, and providing students ample opportunity to apply those principles, online simulations can empower students to overcome this challenge.

Since the simulation was implemented in a remote online learning environment, the survey assessed students' enjoyment of the simulation compared to their general remote online classroom experience and their previous in-person classroom experience. **S_0Q5–Q6** established a baseline to compare their response to **S_fQ4**. **S_0Q5** had an average response of 7.44 ± 0.36. **S_0Q6** had an average response of 6.03 ± 0.44, and **S_fQ4** had an average response of 7.72 ± 0.37 with the most conservative effect size of 0.5846 and 89.3% power (Figure 7(a)).

The distribution of responses to **S_0Q5** indicated a significant preference ($p = .0155$) for in-person learning over remote learning (**S_0Q6**), with 61% of respondents rating their enjoyment of an in-person style at an 8 or higher compared to the 28% who rated a remote style at an 8 (Figure 7(b) and (c)). Despite the simulation being implemented in a remote setting, the responses to **S$_f$Q4** display a similar left-skew distribution with a non-significant difference (p = .5893) to in-person learning, 64% of respondents rating their enjoyment at an 8 or higher (Figure 7(c)), suggesting that "Save the

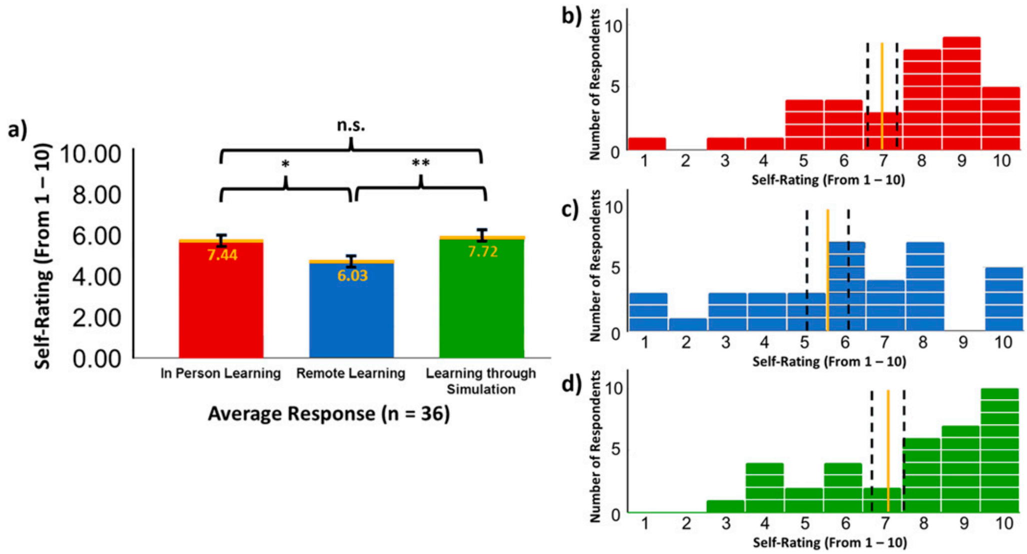

Figure 7. (a) Summary of student self-rated enjoyment of "In Person," "Remote," and "Simulation" Learning. (b) Distribution of responses to **S$_0$Q5** for in-person learning (red). (c) Distribution of responses to **S$_0$Q6** for remote learning (blue). (d) Distribution of responses to **S$_f$Q4** for remote learning with the "Save the World" online simulation (green). Average rating (yellow solid lines) and standard error (black dotted lines) are depicted on each histogram. *n*. s. Denotes not significant, * denotes $p < .05$, and ** denotes $p < .005$.

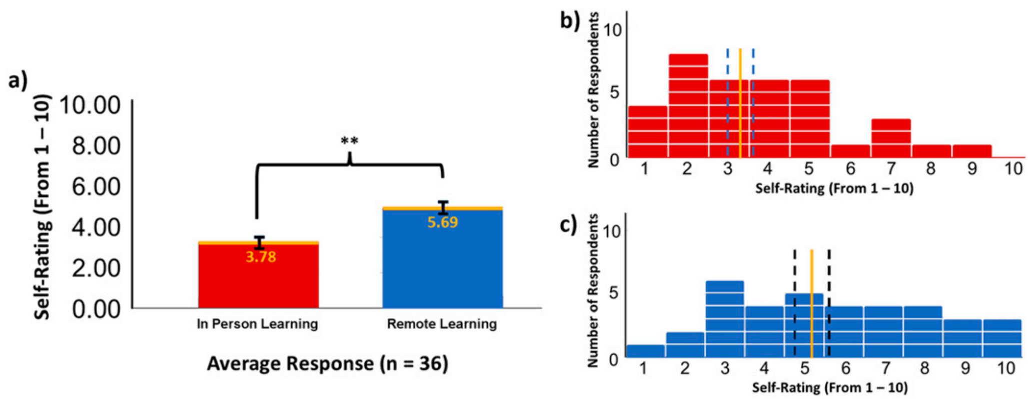

Figure 8. (a) Summary of student-rated difficulty of "In Person" and "Remote" Learning. (b) Distribution of responses to **S$_0$Q7** for difficulties of in-person learning (red). (c) Distribution of responses to **S$_0$Q8** for difficulties of remote learning (blue). Average rating (yellow solid lines) and standard error (black dotted lines) are depicted on each histogram.

World" was able to deliver an educational experience equally enjoyable to that of their standard in-person classroom experiences.

S_0Q7–Q8 gauged students' overall perspectives on the different learning formats, unrelated to the simulation. **S_0Q7** had an average response of 3.78 ± 0.35 and **S_0Q8** had an average response of 5.69 ± 0.42 representing a statistically significant difference (p = .0008) in attitudes with a 0.8234 effect size and 100% power (Figure 8(a)). The distribution of responses to **S_0Q7** indicated a consensus, with 83% of respondents rating the difficulty level at 5 or below (Figure 8(b)). By contrast, **S_0Q8** presented in a histogram format, appears more evenly distributed, with students scattered across all categories from 1 to 10. Approximately 50% of students rated remote learning a 5 or below, while the other 50% rated it a 6 or above (Figure 8(c)). Taken together, this could indicate that a student's success in an online learning environment is more influenced by their ability to access resources. In an in-person setting, all students have daily access to their instructor for support, with more independent learners opting to take advantage, or not. However, in an online setting, students who benefit from additional one-on-one support may find it more challenging to obtain, resulting in the divided perception of the difficulty between lower (i.e. 5 or below) and higher (i.e. 6 or above) ratings as shown in Figure 8(c).

Student reception of the simulation

Regardless of whether the simulation increased the students' understanding of the material, for it to be an effective teaching strategy, it needed to be accepted by the students. **S_fQ6–Q8** measured how the students felt about using simulation tools in their classrooms, specifically if they would want to see it continue to be used in the future. **S_fQ6** had an average response of 7.69 ± 0.39, **S_fQ7** had an average response of 7.97 ± 0.38, and **S_fQ8** had an average response of 8.11 ± 0.36 (Figure 9).

S_fQ9–Q11 gave the students an opportunity to provide written feedback on the simulations. 31 comments were left between these three questions: 28 responses to **S_fQ9** ("What did you like about the simulation?"), 1 response to **S_fQ10** (Is there anything you wish we could include in the simulation to improve them?") and 2 responses to **S_fQ11** ("Additional Comments and Concerns"). Within the 31 specific comments received, four distinct aspects of the simulation repeatedly arose in the students' praise: the visualizations, the interactive element, the instructional help in understanding the topic, and the contextualization of the material in a "real-world" scenario. Table

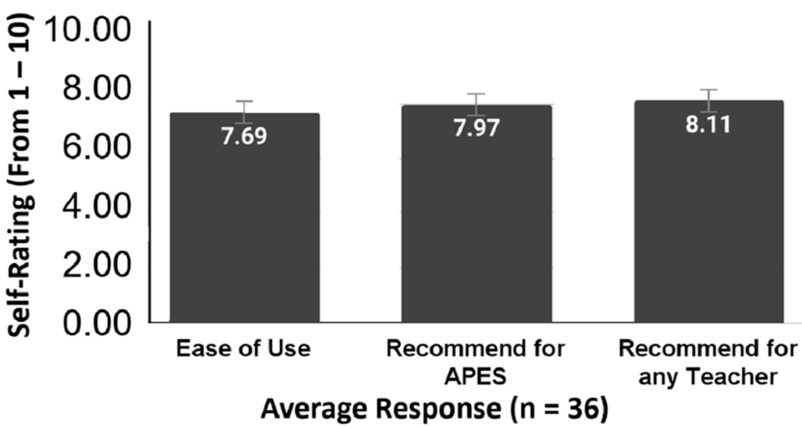

Figure 9. Student ratings of the simulation on three criteria after simulation implementation.

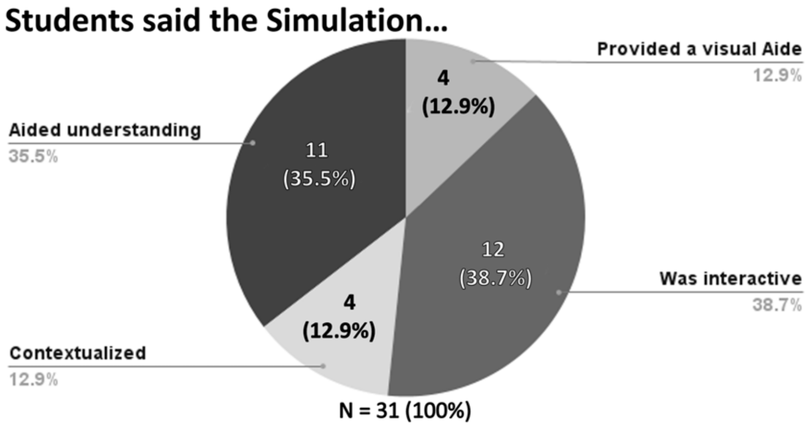

Figure 10. Distribution of positive open-answer comments and responses to **S_fQ9**.

S1 shows the grouping of the students' comments after manual sentiment analysis. Figure 10 shows the distribution of the comments between those four categories.

S_fQ10 had few specific comments, with most responses left blank or some version of "not applicable". The primary complaint was that the users of the simulation could not go back and review content they had already completed. **S_fQ11** also mostly contained blank responses, but contained a few positive comments. One student wrote, "I would like to use the simulations more because I think it was very effective and it made me more interested than a video would, which made it easier to learn the concept," echoing the positive sentiments in the responses to **S_fQ9** about the engaging interactive element of the simulation and how that aided the students' understanding. These responses showed that complaints were mostly simulation-specific while general attitudes toward the use of simulations were positive and encouraging.

Teacher reception of the simulation

UAI instructors who were present for the implementation of "Save the World" responded to the teachers' survey. **T_fQ1** asked about their perception of student engagement in remote learning in general, which the first teacher rated as a 7 and the second teacher rated as an 8. **T_fQ4** asked about student engagement in the simulation. The first teacher rated this as a 9 while the second teacher rated it as a 7. In their response to **T_fQ2**, the first reported their assessment of engagement was "Based on participation and staying on task through transitions," whereas the second described theirs as "the number of students who successfully completed the simulation". The first teacher also commented that "80+% of students participated and tried different methods in the simulator. They were on task and were able to complete the game." The first teacher rated their students' understanding of the various types of renewable resources (**T_fQ3)** after the implementation of the simulation as an 8, while the second rated it as a 9. Comparatively, students rated themselves at an average of 7.06 (Figure 6(a) and (c)), reinforcing the disconnect between instructors' perceived levels of student understanding and students' actual levels of understanding. In response to **T_fQ8,** the first teacher praised "The information that was included on the different renewable resources and how they work," indicating a focus on the instructional aspect of the simulation. The second teacher noted in this section that "the students enjoy games." The first teacher rated their likelihood of recommending the simulation to other APES instructors, as well as their likelihood of to keep using the simulation in the future, both as 10 (**T_fQ9 and T_fQ10**). The second teacher rated both of those categories as a 9. Both teachers rated the difficulty of the simulation as a 2 (**T_fQ7**), indicating that it was easy to use, and the first teacher left a final comment that "The simulator was fun!" (**T_fQ12**).

Meta-analysis on experimental design

The COVID-19 pandemic presented an environment of striking dualism in terms of educational research. While schools were shuttered, much educational research focused on methods for improving learning in this non-traditional setting. Simulations are a compelling form of instructional aid for remote online learning; however, the realities of this type of learning posed unforeseen challenges to traditional assessments of academic achievement, like problem sets or quizzes. The instruments employed in this study heavily rely on subjective metacognitive metrics of student achievement and success, focusing on individual "sense-making, self-assessment, and introspective reflection on what works and what needs improvement" (Klimoski and Hu, 2011). Although there is a wealth of discourse regarding the poor predictive abilities and heterogeneity of self-reported evaluations (Bowers et al., 2005), it is equally important to recognize that these assessments were the standard method for measuring academic performance at the time to adhere to "grading with compassion" policies adopted during the pandemic (Hanley et al., 2020). Online simulations reward creativity and contain no singularly correct answer or approach. Schinske and Tanner found that the fear of making mistakes becomes a barrier to learning (Schinske and Tanner, 2014). By offering a safe space for students to engage, online simulations like "Save the World" foster more genuine interest and robust confidence in STEM subjects, making it suitable for pandemic-era compassionate education.

Like other surveys, response bias may impact the validity of the data. The voluntary and brevity of the surveys, combined with their completion across a single, unsupervised session raises the possibility that students remembered the questions from the pre-survey and recognized them in the post-survey, prompting them to provide certain responses to reflect what they believed should show a significant change (Beebe et al., 2010; Hox et al., 2003). Subtle connotation differences in the wording or phrasing of questions can influence response rates in a self-rated survey, with more introspective prompts exhibiting a deterministic effect on response outcomes (Sanchez and Vargas, 2016). This phenomenon is evident in **S_fQ2** where approximately 30% of respondents rated their ability to articulate the concept of renewable resources to their peers as a 7 out of 10 on the Likert Scale. The prevalence of mid-range post-instruction responses aligns with students' hesitation to rate themselves as fully confident (i.e. 10/10), indicating a humble awareness among the students where they recognize they do not know all aspects of the broad topic (Clauss and Geedey, 2010). Although the tailored objectives in "Save the World" create an engaging, focused activity, they implicitly encourage students to consider what is not being shown, and what the developers may be deliberately obscuring to smooth the game mechanics. For instance, the simulation never prompts the player to consider the storage capacity of a particular renewable energy resource. Additionally, it is also important to consider the UAI respondents, who are younger (i.e. 9th - 10th grade) students, may have viewed the researchers presenting the surveys and directing them to the simulation as authoritative figures, leading them to give answers they believed the researchers wanted to hear, rather than genuine opinions (Mazor et al., 2002).

Despite these concerns, the survey exhibited low rates of non-response, mid-to-large effect size (i.e. $d \geq 0.6$), and strong post hoc statistical power (i.e. $\geq 80\%$) contributing to its good internal validity. Out of the 68 total students and two teachers across two classes, 49 students completed the pre-survey (i.e. 28% non-response), 45 completed the post-survey (i.e. 34% non-response), and both teachers completed the teacher's survey (i.e. 0% non-response). These response rates are typical for multi-stage instruments without tangible incentives, where subsequent rounds of data collection usually show higher non-response rates than in the initial wave (Bose, 2001). Furthermore, the data analysis was conducted by separate individuals from those administering the module and the surveys. By minimizing the risk of bias, blind data analysis helps maintain the integrity of the study, strengthening its internal validity, and leading to more accurate and reliable conclusions (MacCoun and Perlmutter, 2015).

Conclusion

Online simulations are versatile teaching tools

As a versatile cloud-based teaching tool, "Save the World" online simulation aimed to achieve two main pedagogical goals: (1) to illustrate the concept of renewable energy resources as sustainable alternatives to fossil fuels and (2) to explain the mechanics of various types of energy sources and their power generation processes. Through comparing the differences in pre- and post-activity surveys, students' self-efficacy in explaining sustainability and renewable resources increased significantly, indicating its success as a viable method of introducing new material. Despite their deviation from the traditional teacher-centric classroom model, both students and teachers received the simulation positively, highlighting its interactive elements, striking visual aids, and effective translation of APES material to real-world applications. On average, students rated their enjoyment of the online simulation almost as high as their enjoyment of the traditional in-person learning, despite reporting lower enjoyment of the online teaching format. This seems to indicate that the engaging, interactive elements of the online simulation counteract the detached nature of an online learning setting, encouraging students to participate and remain engaged without physical attendance. The simulation also allowed for independent and anonymous work, fostering self-expression, which can be more rewarding than traditional lessons in some cases (Çakıroğlu and Güler, 2021). Although this strategy may relegate the instructor to a secondary role, cloud-based online simulations like "Save the World" seem to be an effective method for introducing, contextualizing, and demonstrating new concepts in APES curricula. Therefore, it could be beneficial to incorporate simulation-based learning sessions in regular instruction even in non-remote settings.

Avenues for further research

Although our team did not solicit demographic data in these surveys, it is important to note that UAI is a single-sex institution with an all-female student body composed of 58.8% Black or African American, 17.2% Latinx, 11% White, and 8.5% Asian or Asian/Pacific Islander (U.S. News Ranking 2024). Future work should aim to expand the study to more schools to achieve a better representation of students of different sexes or ethnicities. In addition, as students rated their enjoyment of the simulation similarly to an in-person session, it could be interesting to compare the impact of "Save the World" when conducted synchronously with instructor guidance versus asynchronously (Carr, 2014). While conducting a longitudinal study on students' AP test scores or vocational choices is not currently feasible, it would be intriguing to investigate how these simulations impact these dimensions of student achievement.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the National Science Foundation; DMR 1728858, DMR 2203680 and MSN 2304958.

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Data availability statement

All materials that were used to develop a conclusion can be found in the supplemental materials for this manuscript.

Supplemental Material

Supplemental material for this article is available online.

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Andrew Wang earned his B.A. in Molecular and Cell Biology from the University of California Berkeley in 2017, as well as a Master of Translational Medicine degree jointly from the University of California Berkeley and the University of California San Francisco in 2018. He then moved to the State University of New York-Downstate Medical Center, where he is an MD/PhD candidate in Biomedical Engineering. Currently, his doctoral research is being completed under the supervision of Professor Jin Kim Montclare at New York University, where he is studying the use of self-assembling proteins for drug delivery and molecular imaging.

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