ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37440

Door-Alarm Lab: Integration of Engineering Design in a Simulation-based Learning Environment for Pre-Service Elementary Teachers

Zeynep Akdemir

Fourth year Ph.D. student studying in Science Education at COE and working in Engineering Education at Purdue University. Interested in researching engineering design thinking, curriculum development, and educational psychology

Door-Alarm Lab: Integration of Engineering Design in a Simulation-based Learning Environment for Pre-Service Elementary Teachers

Introduction

We live in a century where virtual realities like Metaverse are starting to occupy our daily lives. The more we enjoy the technical aspects of these computerized mannequins, probably, humankind will no longer consider different technological tools as add-ons for their fields. For example, simulation is one of these specialized tools that are no longer viewed as a novelty in various domains of higher education (e.g., Aebersold, 2018; Kim et al., 2001). It is because simulation-based learning tools allow students to visualize physical situations interactive (citation). From a theoretical point of view, simulations promote constructivist learning and support diverse learning styles that can be more visually oriented.

Studies that have already looked at the use of physics education technology, aka PhET, provided evidence that computer simulations are beneficial to learning STEM-based content (e.g., Bandoy et al., 2015; Zacharia & Anderson, 2003). Prior research also showed that simulation experiments could enhance college students' learning as much as hands-on experiments (Finkelstein et al., 2005). However, there have been few efforts to use simulations to facilitate the integration of engineering design with the scientific inquiry for non-STEM majors. In this vein, our study discusses the importance of interactive simulations for teaching and learning a challenging STEM-based domain – physics – specifically for the college of education students (e.g., Koponen & Nousiainen, 2012). We implement an instructional unit that integrates engineering design with scientific inquiry in a physics course for future elementary teachers. Students work in groups using a PhET simulation (DC Circuits Kit). We use a research-based test, DIRECT (Engelhardt & Beichner, 2004) to compare student understanding before and after completing the unit. Our main research question is: Is there a statistically significant improvement in student understanding of circuits before and after the unit?

Literature Review

Existing studies provided evidence that learning about natural world phenomena can better be done virtually (Finkelstein et al., 2005). It means that computer simulations in actual scientific equipment are becoming integral parts of recitations or laboratories (Lee et al., 2008). Studies done with different age groups showed the positive impact of computer simulations on learners' mastery of concepts and ability to integrate information (e.g., Sari & Wahono Widodo, 2021; Triona & Klahr, 2003; Zacharia & Anderson, 2003). However, there have been few efforts to use simulations to facilitate the integration of engineering design with scientific inquiry (e.g., Capobianco et al., 2013; Magana et al., 2021). For example, Magana and colleagues (2021) provided a multiple case study in which different age groups were engaged in engineering design with computer-aided simulation to learn science content. The third case of their study was explicitly focusing on pre-service teachers who discovered the concept of heat transfer embedding an engineering design challenge that asked students to build an energy-efficient home under certain requirements. Their study implemented a specific pedagogical approach in which students were expected to (a) explore science concepts, (b) discuss and develop scientific explanations with the instructors and peers, and (c) elaborate on the learned scientific concepts through engaging engineering design challenges. Although the main focus of their study was to compare different age groups, the promising result was students' increased knowledge of the targeted science concepts and functionality of their design project. To our knowledge, this study was the only one focusing on teaching the integration of engineering design with a scientific inquiry via using a computer-aided simulation. Therefore, we hope that our research would contribute to the existing field, which emphasizes understanding the effects of these blended contexts into science and engineering.

Engineering Design for Future Elementary Teachers

The Framework of K-12 Science Education (NRC, 2012) and Next Generation Science Standards (NGSS, 2013) calls for unified learning environments that promote interdisciplinary work culture across STEM disciplines. The unification of STEM-based learning environments necessitates educators and researchers to go beyond teaching science and engineering through a simple combination. Instead, a recent innovation in teaching science and engineering looks for educators to promote a cultural climate where disciplinary concepts are infused with scientific inquiry, engineering design, and 21st-century technological skills. However, effective teaching and learning in engineering-design-based settings are challenging to grasp. Learners are required to use their content knowledge to fulfill their design decision-making. To achieve this goal, teacher candidates are the disseminators of the domain-specific knowledge to future generations. Therefore, the effective use of educational technologies (i.e., computer simulations) for teachers and teacher candidates can facilitate learners to test the multiple features of their design projects with various data visualizations. This study generated a five-week-long unit integrating engineering design with scientific inquiry in a simulation-based environment based on this rationale. The overarching research question is: To what extent did pre-service elementary teachers' understanding of electric circuits change after participating in a five-week-long lesson?

Methods

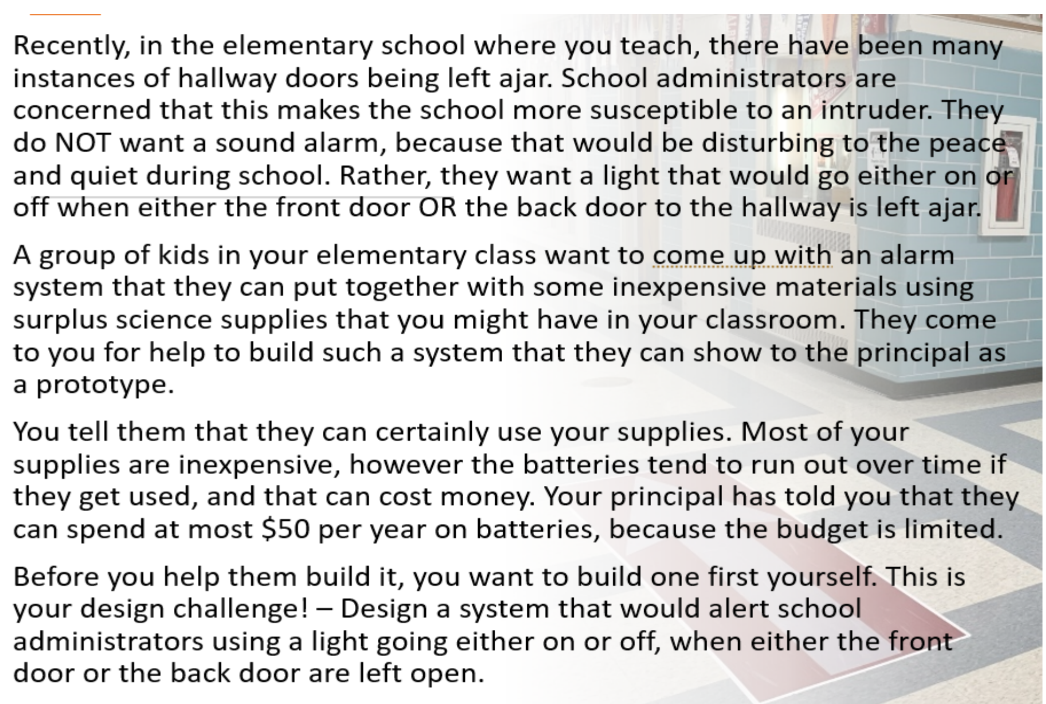
This section presents the instructional context and the research design.

Instructional context

The instructional design was embodied in a design challenge that amalgamated the engineering design cycle (Capobianco et al., 2013) with the 3E-learning cycle (Karplus & Butts, 1977, Rebello, 2019). A technologically scaffolded undergraduate course was redesigned to include learning outcomes focusing on integrating science learning with engineering practices. The PhET™ Circuit Construction Kit: DC was used by participants to complete experiments on lighting a light bulb with a battery and single wire, measuring charge flow & energy changes, simulating a circuit, understanding the functions of circuit elements (i.e., resistor, power source), comparing parallel and series circuits, and changing the resistance of a bulb. The unit commenced with an engineering design challenge that asked pre-service teachers to design a light alarm system to set off an alarm when either a front or a rear door to a school hallway was left ajar.

Figure 1

Design Brief



Students attempted the design challenge based on their intuitive prior knowledge of circuits. This part of the lesson unit can be considered as the engagement phase of the unit. The laboratory sessions (explore phase) occurred before the lectures (explain phase) as per the 3E (Explore-Explain-Elaborate) version of the learning cycle (Karplus & Butts, 1977; Rebello, 2019). The design challenge was followed by four weeks of explore-explain sequences to facilitate students to learn the science concepts needed to address the challenge. At the end of the unit, students returned to the challenge where they applied their ideas to the engineering design challenge. The challenge was similar but more complex than the initial challenge, so students who had completed it based on their prior knowledge accommodated new design criteria and constraints (expansion phase). The unit included a 50-minute lecture and two 2-hour and 50 minutes lab sessions each week.

Research design

We employed a survey-based cross-sectional research design in which a diverse group of subjects is surveyed at the same time (Ary et al., 2019).

Participants and context

The purposive sampling method was used to choose a representative sample of the college of education students—the pre-service teachers (n = 92) selected from an elementary education program in a Midwestern public higher education institution. Data collected for this study occurred in the Fall of 2021.

Data sources

Data was collected from pretest and posttest assessments of specific concepts in electric DC circuits. Assessment items consisted of 29 multiple choice questions directly from a reliable and valid The Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT)

(Engelhardt & Beichner, 2004). The DIRECT test was administered at the beginning and end of the unit. The assessment items' scoring was dichotomy-based, with 1s for correct responses and 0s for incorrect answers. The internal consistency of the DIRECT Test for our sample as measured by Cronbach's alpha coefficient was .33, which is considered low. This low value can be due to a low number of questions, low inter-relatedness between items, or heterogeneous constructs (Taber, 2018), which is a concern of future researchers who would like to do further pilot testing of the instrument.

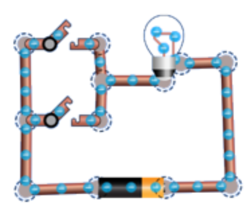
We also collected student responses from the transfer task that students completed as part of their end-of-unit exam. The transfer task was based on the same concepts as the design challenge. There were two versions of the transfer task, one for each version of the exam. Figure 2 shows each version of the task and the expected correct response to the task.

Figure 2

Two Versions of The Transfer Task with The Correct Solutions

VERSION A: Suppose you have two doors. Each door is attached to a switch, such that when the DOOR is OPEN, the SWITCH is OPEN. Sketch a circuit with one light bulb, one battery, and two switches, such that the light bulb comes ON <u>when EITHER door is CLOSED, AND when BOTH of doors are CLOSED</u>. Explain your reasoning.

If EITHER or BOTH switches are CLOSED, there will be a path for the electrons from the battery, through the light bulb and back to the battery.
This means that in the circuit shown, the light bulb will come ON when EITHER or BOTH switches are CLOSED.



VERSION B: Suppose you have two doors. Each door is attached to a switch, such that when the DOOR is OPEN, the SWITCH is OPEN. Sketch a circuit with one light bulb, one battery, and two switches, such that the light bulb only on comes <u>ONLY when BOTH doors are OPEN</u>. Explain your reasoning.

If ANY ONE or BOTH switches are CLOSED, there will be a path for the electrons from the battery, through that SWITCH and back to the battery.
Because current takes the path of least resistance, when either one of the switches is closed, the current will go through that switch and nothing will go through the bulb, causing the bulb to turn OFF
This means that in the circuit shown, the light bulb will come ON ONLY when BOTH switches are OPEN.

Data Analysis

Descriptive statistics were used to identify the mean, standard deviations, central tendency, and data spread. Paired sample t-test was used to determine the conceptual learning gains of the participants. Mean scores of both pre-and post-assessments were standardized to reflect accurate percentages.

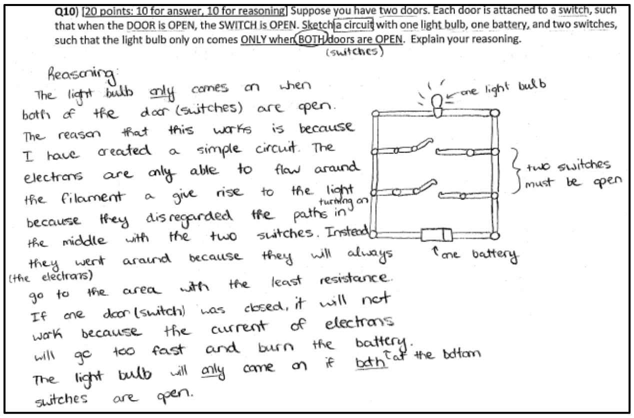
Results

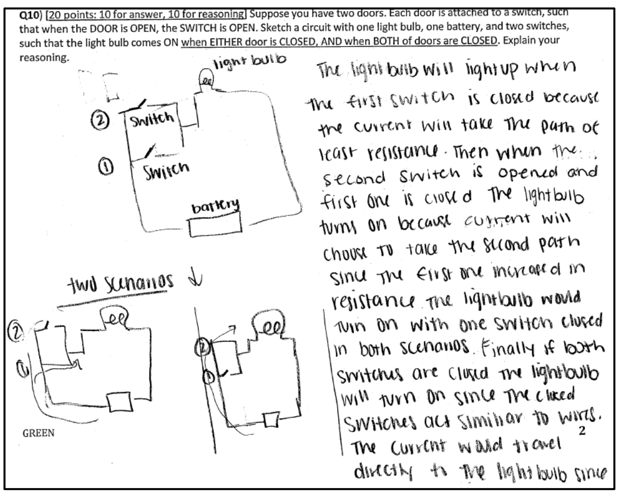
All the students scored less than 50% of the pre-assessment items, but students who could answer more than half of the questions were slightly higher in post-assessment. Paired-test results showed that students' post-scores (M = 6.80, SD = 2.21) were significantly higher than their pre-scores (M = 9.00, SD = 2.66), $t(91) = 7.20$, $p < .01$, d = 2.92.). This finding implies that simulation- and engineering design-based science instruction for pre-service teachers were helpful to improve their science content understanding on electric circuits.

Student solutions to the transfer task were analyzed for correctness in response as well as in reasoning. A solution was deemed correct only if the student was able to provide both the answer and the reasoning to support the solution. Our results showed that about 64% (28 out of 44) students who completed Version A were able to correctly solve the transfer task and about 73% (36 out of 49) students who completed Version B were able to correctly solve the transfer task. Overall, about 69% (64 out of 93) students were able to correctly solve the transfer task. Examples of the correct solutions for both versions are shown in Figure 3.

Figure 3

Example of Correct Student Answer and Reasoning for Version A and Version B





Discussion

This study investigated the change in pre-service elementary teachers' understanding of electric circuits after implementing simulation-based engineering design challenges with the 3E-learning cycle. The learning goal was to promote science content with engineering practices by engaging students in design challenges enabled by a PhET™ simulation. After this simulation-based pedagogical implementation, the study results suggested statistically significant gains in students' science content knowledge. Contrary to the previous study findings that used a similar pedagogical approach (e.g., Magana et al., 2021), our results were able to show that the use of computer simulation in teaching electric circuits to college students was effective for science and engineering learning. On the other hand, our findings supported the prior research evidence that the effectiveness of these computer-aided tools depends on careful preparation, knowing, and implementing the stages of use of the media (e.g., Haryadi & Pujiastuti, 2020).

Further we also found that a significant percentage (about 69%) of students were able to correctly answer and reason about the transfer task. This finding further demonstrates that the engineering design challenge and scientific inquiry activities that students completed in a computer simulation enabled our student sample to transfer their conceptual understanding of DC circuits to novel design tasks.

Implications

Our study results have several implications for research and pre-service elementary level teacher education. Our findings statistically showed that PhET™'s media simulation on electric DC circuits was supportive for pre-service teachers to conduct their experiments as they do with hands-on materials. They were able to observe to situate their understanding of electric systems in real-world settings. However, future researchers can conduct the same research design with a large sample to ensure that the simulation-based engineering design curriculum implementation has the same impact. Our study's engineering design-based pedagogical content asked pre-service teachers to generate a light alarm system that prevents school hallway doors from being left ajar. In this vein, further studies can look at specific parameters such as design criteria and constraints to investigate the level of engineering design thinking of the pre-service elementary teachers. In addition, our college-level course had to fit a 50-minute weekly lecture with a two-hour weekly lab content that obliged the course instructor to provide less content-based information. The ratio between lecture and lab work duration could impact some students' performance, specifically for those who did not have sufficient prerequisite knowledge in electric circuits. For future research purposes, researchers may consider employing mixed-method designs to find a chance to dive deeper into students' understandings of the engineering-design process and their application of the PhET™ Circuit Construction Kit: DC.

Conclusion

The wide use of computer-aided simulations in physics teaching positively affects college students' understanding of natural phenomena. Electric DC circuits are one of the topics that have been taught through the PhET™ simulation. Still, the empirical studies investigating pre-service elementary teachers' science knowledge development were lacking. Therefore, our study attempted to explore the effect of using the PhET™ Circuit Construction Kit: DC in a five-week-long college course. Our findings suggested that teaching electric DC circuits via the PhET™ simulation media helps pre-service teachers to make relationships between their real-life phenomena and underlying scientific knowledge based on their increased post-assessment scores as well as their performance on a transfer task.

References

Aebersold, M. (2018). Simulation-Based Learning: No Longer a Novelty in Undergraduate Education. *OJIN: The Online Journal of Issues in Nursing, 23*(2).

Ary, Jacobs, L. C., Sorensen, C. K., & Walker, D. A. (2019). *Introduction to research in education (Tenth edition)*. Cengage.

Bandoy, J. V., Pulido, M. T., & Sauquillo, D. J. (2015). The effectiveness of Using PhET Simulations for Physics Classes: A Survey. *Conference: International Conference on Engineering Teaching and Learning Innovation (ICEE-PHIL2015).*

Capobianco, B. M., Nyquist, C., & Tyrie, N. (2013). Shedding light on engineering design. *Science and Children, 50*(5), 58.

Engelhardt, P. V., & Beichner, R. J. (2004). Students' understanding of direct current resistive electrical circuits. *American Journal of Physics, 72*(1), 98-115. https://doi.org/10.1119/1.1614813

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., & S, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics - Physics Education Research*.

Haryadi, R., & Pujiastuti, H. (2020). PhET simulation software-based learning to improve science process skills. *In Journal of Physics: Conference Series (Vol. 1521, No. 2, p. 022017)*. IOP Publishing.

Karplus, R. & Butts, D. P. (1977). Science teaching and the development of reasoning. *Journal of Research in Science Teaching, 14,* 169-175.

Kim, J.-H., Park, S.-T., Lee, H., Yuk, K.-C., & Lee, H. (2001). Virtual Reality Simulations in Physics Education. *Interactive Multimedia Electronic Journal of Computer-Enhanced Learning, 3*(2), 1-7.

Koponen, I., & Nousiainen, M. (2012). Pre-service physics teachers' understanding of the relational structure of physics concepts: Organising subject contents for purposes of teaching. *International Journal of Science and Mathematics Education, 11*, 325-357.

Lee, Y.-F., Guo, Y., & Ho, H.-J. (2008). Explore effective use of computer simulations for physics education. *The Journal of Computers in Mathematics and Science Teaching, 27*(4), 443-466.

Magana, A. J., Chiu, J., Seah, Y. Y., Bywater, J. P., Schimpf, C., Karabiyik, T., . . . Xie, C. (2021). Classroom orchestration of computer simulations for science and engineering learning: A multiple-case study approach. *International Journal of Science Education, 43*(7), 1140-1171.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press.

Rebello, C. M. (2019). *Scaffolding Evidence-Based Reasoning in a Technology Supported Engineering Design Activity [Paper presented]*. The 13th Conference of the European Science Education Research Association (ESERA).

Sari, D. P., & Wahono Widodo, M. (2021). Computer simulation feasibility for Newton's Law learning. *Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12*(6), 4880-4890.

Taber, K. S. (2018). The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education, 48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Triona, L. M., & Klahr, D. (2003). Point and click or grab and heft: Comparing the influene of physical and virtual instructional materials on elementary school students' ability to design experiments. *Cognition ad Instruction, 21*(2), 149-173.

Zacharia, Z. C., & Anderson, O. R. (2003). The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. *American Journal of Physics, 71*(6), 618-629.