Teaching Engineering for Democracy: Equipping Social Studies Teachers in Grades 6-12 to Bring Industrial and Systems Engineering Principles into Humanities Classrooms

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Rachele Limberakis brings a breadth of experience in education, spanning elementary classrooms, STEM instruction, and educational technology leadership. She has supported educators through professional learning, guided district technology initiatives and curriculum development, and integrated innovative and assistive technologies into instruction. A frequent presenter at state and national conferences, she has received multiple grants and recognitions. Her work focuses on creating engaging, interdisciplinary learning experiences that help students explore interests and consider diverse future pathways, including her work with the EDI team.

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Caroline Stabile is the Director of GEMS-Net, a partnership between the Feinstein College of Education at the University of Rhode Island and school districts across Rhode Island. Established in 1995, GEMS-Net advances science education through sustained, collaborative partnerships. Since 2023, GEMS-Net has partnered with the UConn-URI Navy STEM Coalition to design instructional resources and professional learning experiences that connect classroom science to current STEM research, with the goal of expanding students' awareness of career and workforce pathways.

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Gretchen A. Macht, Ph.D., is an Associate Professor in the Department of Mechanical, Industrial & Systems Engineering at The University of Rhode Island, where she is the Founder and Executive Director of the Engineering for Democracy Institute. The Engineering for Democracy Institute (EDI) is a collective

of students, professors, and election experts focused on improving operational efficiency in U.S. elections. Using engineering principles, EDI has created tools and guidelines, helped implement legislative changes, and addressed current election challenges, so far having a nationwide impact in 18 states, representing over 26 million registered voters. Dr. Macht is an HFES Science Policy Fellow and the 2024 URI Advanced Career Faculty Research and Scholarship Excellence Award.

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Abstract

This paper presents data on the efficacy of teacher professional development for classroom implementation of K-12 curricular resources for integrating industrial and systems engineering into social studies classrooms to demonstrate the intricate relationship between STEM topics and civic responsibility. The project is based on the module developed through the collaboration of industrial and systems engineering faculty and graduate students working with K-12 science teachers, and has been adapted for different grade levels. Students engage in the engineering process through activities aligned with Next Generation Science Standards. Through the simulated voting experience, students test, redesign, and collect data on various iterations of spatial layouts, followed by a virtual visit to a university's engineering lab. While originally envisioned as a means of introducing current university-level research to K-8 general studies and science classrooms, the program's applicability to social studies, civics, and government classrooms in higher grades enabled further adaptation of this work. The classroom lesson expands student understanding of engineering fields to include industrial and systems engineering, as well as recognize its impact on their communities, thereby expanding the scope of engineering education into K-12 social studies classrooms. Teacher professional development may increase the adoption of these multidisciplinary curriculum resources by equipping social studies teachers with basic knowledge of the engineering principles and applications imparted in the lesson. A one-day teacher professional development workshop for Grades 6-12 social studies teachers was held at a large, public R1 university. Surveys on teacher knowledge of engineering principles and confidence in teaching an engineering lesson were collected before and after the workshop. Survey results indicated that teacher knowledge of engineering principles and confidence in teaching an engineering lesson increased following the professional development workshop. Results will help to improve future adoption and delivery of industrial and systems engineering lessons in K-12 social studies classrooms through civics-based lessons, in which students learn how engineers can directly improve the efficiency and effectiveness of voting systems, diminishing the potential for disenfranchisement.

Introduction

In order for democracy to be representative of the people, United States' citizens elect the individuals who will represent them in various areas of government. Since many voters in the United States will first be eligible to vote during or immediately after their final year of high school at 18 years of age, it is critical that these students are taught about the electoral process and civic duties in their school curricula. Traditionally, these lessons have been taught in either social studies or civics courses from a historical or current events perspective. However, research conducted by the Engineering for Democracy Institute (EDI) showcases the interdisciplinary

relationship between the electoral process and industrial and systems engineering. In an effort to convey this relationship to K-12 students, EDI partnered with the Guiding Education in Math and Science Network (GEMS-Net) and the UConn-URI Navy STEM Coalition to develop a resource for teachers to use in either social studies, civics, or science classes to teach students about the systems behind the voting process. Engineers can directly improve the efficiency and effectiveness of voting systems and vote-by-mail processing, thereby supporting a more informed, engaged, and just society in which the potential for disenfranchisement is diminished.

The Engineering for Democracy Institute is an academic research institution at the University of Rhode Island. Founded in 2017, EDI applies engineering techniques and methodologies to assist election officials across the United States in navigating the election and voting process. This multidisciplinary team includes industrial and systems engineers and computer scientists, and leverages partnerships with political scientists and psychologists to develop a unique approach to understanding election systems through quantifiable data. Through data-driven findings and nonpartisan research, EDI has helped voters and counties in over one-third of the states in the country, contributing to a more efficient and effective democratic process.

EDI's work began following the 2016 general election when the Rhode Island Secretary of State sought assistance in understanding how industrial and systems engineering applications could be used in elections to reduce the long lines that were reported during in-person voting that year, thereby reducing voter disenfranchisement. Through techniques such as resource allocation, simulation, and facility layout planning, EDI assisted the Rhode Island Board of Elections in improving in-person polling locations for the 2018 midterm election.

Since its inception, EDI has collaborated with state and county election officials from across the country and has expanded its research efforts to include other election-related areas beyond in-person voting, such as vote-by-mail processing and warehouse management. As their research impact grows, EDI has begun developing publicly available tools and applications for election officials to use in preparation for upcoming election cycles. These tools are free and utilized by election officials to better understand a variety of factors and resource requirements that impact voter experience and the election process, including but not limited to understanding voter wait times at in-person polling locations, warehouse space requirements for election materials and equipment, accessible voting system requirements per location, and calculating overall processing times for the vote-by-mail process. EDI has also made a concerted effort to provide professional development opportunities and education for engineers and other STEM professionals who are interested in contributing to the improvement of their own local voting jurisdictions.

The UConn-URI Navy STEM Coalition is a collaboration between two R1 universities to support workforce development and outreach efforts to recruit and retain the next generation of employees for the regional defense eco-system. Defense and technology companies are facing severe workforce shortages due to a large cohort of employees who have reached or are nearing retirement age, simultaneously with expanding production demand. The Navy STEM Coalition brings together industry partners, academia, and K-12 education professionals to address these workforce shortages by developing and delivering STEM activities and curricular modules that engage young learners. In particular, the custom modules that have been developed link current university research with industry careers and Next Generation Science Standards (NGSS) at specific grade levels, with age-appropriate curriculum enhancement artifacts [1], [2]. The goal is

to demonstrate to K-12 learners that the content they are learning in their classrooms today is directly linked to opportunities they could pursue in the future. Historically, these modules have all been exclusively associated with STEM classroom learning and NGSS standards. The collaboration with EDI has provided a unique opportunity to bring together STEM learning and social studies and civics lessons that center around the democratic process of conducting elections and voting in a representative government.

The Guiding Education in Math and Science Network is a research-practice partnership involving educators for Grades K-8, school leaders from 15 districts across Rhode Island, community partners, and faculty in Education and STEM fields at the University of Rhode Island who are committed to the continuous improvement of science teaching and learning. GEMS-Net collaborates with each district to ensure that all teachers have access to high-quality curriculum materials and that all GEMS-Net teachers participate in curriculum-based professional learning workshops throughout the school year. The GEMS-Net team also works with teachers in these schools through instructional coaching. A key component of GEMS-Net's model is the Teacher-in-Residence program. GEMS-Net identifies and selects teachers-in-residence from a team of teacher leaders to serve for a two-year appointment. Successful candidates for the teacher-in-residence position demonstrate exceptional pedagogical skills and leadership potential to support their colleagues and schools in science education.

GEMS-Net's partnerships with the Navy STEM Coalition and EDI help achieve one of its strategic goals, which is to ensure that students at all grade levels are able to make meaningful connections between what they are learning in their classrooms and potential college and career pathways. Children need to be able to imagine possibilities for their future and see themselves reflected in the variety of careers available to them [3], [4]. Students, as early as preschool and early elementary school, make decisions about whether they will pursue or eliminate certain career tracks, and sometimes overly constrain their options before they have personally experienced occupational barriers. This can occur by the end of developmental stage 3 (ages 9-13), and thus, it is critical to reach students early and often to promote the possibilities of pursuing STEM career paths [5], [6]. Other research has identified critical grade levels through which the STEM pipeline operates and how outreach can expand the pipeline. STEM outreach can be highly effective at engaging students quickly, with successes as early as kindergarten, and details the impacts at different grade levels [7]. Teachers' perceptions of engineering have been shown to change through participation in engineering education programs during pre-service training [8], cross-disciplinary professional development [9], [10], or in extended STEM integration programs specifically for current classroom teachers, including Research Experience for Teacher programs [11], [12]. The partnerships between the programs at the University of Rhode Island are built on best practices to create trusted connections for teachers with university research and outreach programs and to provide pre-packaged but adaptable materials that are easy to implement in the classroom [13]. Specifically, when highlighting the connections between STEM and civics, research has shown through a systematic review that integrating design-thinking and technology can enhance student interest and engagement, and that teacher training is essential [14].

The collaboration with EDI specifically helps broaden teachers' and, therefore, students' understanding of the breadth of what engineers do and how engineering can be used to design

systems and processes that improve people's experiences in meaningful ways, such as voter access and experience at voting locations. EDI's research bridges the gap between STEM and civics by strengthening students' civic agency and engaging them in iterative problem-solving processes. Students and teachers ideally gain a renewed sense of responsibility to the electoral process, as well as a new framework from which they can address challenges across a variety of subjects. Students learn how vital voting is to the United States' democratic process and, by connecting it to EDI's research, they gain insight into how, as engineers, they can make their community more accessible and efficient for everyone.

Resource Development and Professional Learning Workshop

Through the collaboration between EDI, GEMS-Net, and the Navy STEM Coalition, a multifaceted module was developed to teach K-12 students about the in-person voting process and how the work of industrial and systems engineers can improve voter experience and wait times. The inspiration for this module was to showcase to students the broad applications of industrial and systems engineering outside of traditional manufacturing fields, specifically highlighting its applicability to the social sciences.

The developed module includes a video, an in-class simulation activity, student tasks focused on system improvement and data analysis, and a teacher's guide to assist with implementation. The language used in the video and related tasks for classroom use was collaboratively built utilizing the engineering and election competencies of EDI, ensuring content accuracy, and the pedagogical expertise of GEMS-Net staff, to align with accessibility and connected standards (i.e., Next Generation Science Standards [15], Common Core State Standards for Mathematics [16], Rhode Island Social Studies Standards [17], and Connecticut Social Studies Standards [18]) for specific grade levels.

To encourage the implementation of these resources in social studies and civics classrooms, EDI, GEMS-Net, and the Navy STEM Coalition co-hosted a professional learning workshop for middle and high school social studies and civics teachers. After a brief introduction to industrial and systems engineering and EDI's work, teachers participated in the in-class simulation activity as student learner. The multi-round human simulation emulates an in-person polling location with three voting steps: check-in, ballot marking, and ballot scanning. The initial round simulates a poorly designed polling location with only one check-in station, one ballot-marking station, and one ballot scanning station. Students complete the simulation as "voters" and time how long it takes them to complete the process from when they enter the system (i.e., enter the line to check-in) until they exit the system (i.e., "leave" the polling location after submitting their ballot into the scanner). Following the completion of all learners through the system, a group discussion was held to assess bottlenecks and inefficiencies, which led to a conversation about modifying the system to improve the voter experience and decrease voter wait times – components that, in practice, help reduce voter disenfranchisement.

After their discussion about improvements, the participants redesigned the system and reallocated resources. Another iteration of the simulation was then run utilizing the group's consensus model of a new design. Upon completing the simulation again, learners analyze their experience and the impact of the revised system, highlighting the effects of industrial and systems engineering on in-person voting systems.

The workshop participants were then introduced to the video resource, which features the Executive Director of EDI and a graduate student as they explain industrial and systems engineering, the elements of a system, the steps in the voting process, and EDI's research that combines industrial and systems engineering and elections. It utilizes an interactive, asynchronous approach to provide students and teachers with a unique lens into the field of engineering. The video also includes embedded moments for teachers to pause throughout to facilitate classroom discussion. Teachers also had the opportunity to review the online resources to familiarize themselves with the structure and implementation process. To ensure the transfer of learning to the classroom, time was spent exploring ideas for classroom implementation and strategies for different learners. Additionally, teachers were encouraged to request support from EDI and GEMS-Net with future classroom implementation.

Teachers then attended two panel discussions. The first discussion was with the Executive Director of EDI, who shared the program's history, personal experiences in a STEM field, and stories from past projects that showcased how industrial and systems engineers have improved the election process. Later in the day, a second panel was held, featuring multiple engineering graduate students with different engineering backgrounds. These students shared the paths they took to earn their degrees and their personal interests, providing teachers with an opportunity to consider the multiple points of entry into the engineering field.

The workshop concluded with a focus on sharing engineering experiences with the teachers, as part of a continued effort to encourage them to share this career with their students. Teachers were invited into EDI's lab, where they saw 3D modeled simulations of voting locations, and tried hands-on activities related to industrial and systems engineering and EDI. Teachers were given the opportunity to walk-through an in-person voting simulation using a virtual reality headset, see 3D models of real polling locations created by EDI, explore learning curves and their impact on task completion times using LEGO builds [19], and use web-based tools developed by EDI for election officials to assist with voting location layouts and voter wait time estimations. These experiences are particularly important for these teachers as they are not typically exposed to engineering components or STEM-related experiences. Through this workshop, teachers can expand their understanding of industrial and systems engineers' impact on society and share this knowledge with their students, introducing them to new potential career pathways and a new lens for viewing the world.

Survey Implementation

At the beginning of the professional learning workshop, participating teachers were recruited to participate in a voluntary IRB-approved research study to understand how the workshop's events improved their understanding of engineering principles, careers, and research, as well as their overall confidence in teaching an engineering-based lesson. The voluntary study included a pre- and post-survey to be filled out by participating teachers at the beginning and end of the workshop. In total, eight participants completed the pre-survey, which was administered online through Qualtrics, and it took an average of 2.5 minutes to complete. The brief survey included questions about the teacher's current school district, teaching level/grade, and specific course area within social studies and civics. Teachers were also asked to share any prior experience in the STEM fields or in teaching STEM-based courses. The survey concluded with a series of statements related to their confidence in teaching and their understanding of engineering and

social studies topics, which participants responded to using a six-point Likert scale (i.e., strongly disagree, disagree, slightly disagree, slightly agree, agree, and strongly agree). See the Appendix for all pre-survey questions.

Following the workshop, participants were asked to complete a post-workshop survey, in which they reevaluated their responses to the same six-point Likert scale questions from the pre-survey based on their workshop experience. The questions included in the post-survey have been identified with an asterisk in the Appendix. Of the original eight respondents, only six completed the post-survey, which was also administered online via Qualtrics and took an average of 1.6 minutes to complete.

Survey Results

All of the teachers who elected to participate in the research study are teachers in either Rhode Island or Connecticut school districts who teach social studies, history, civics, and/or government at the middle school ($n = 5$) or high school ($n = 2$) level, with the exception of one participant who is a university-level education professor. Teachers were asked to share their prior experiences in STEM or in teaching STEM subjects. All eight respondents indicated that they had never taught a STEM subject, and six reported having no personal STEM-related experience. One respondent reported limited STEM experience, but only in small team activities. Another respondent referenced personal experience with geography/GIS systems.

Using a six-point Likert scale, teachers indicated their confidence in teaching social studies topics at their grade level, as well as engineering topics. With the exception of one participant, all respondents indicated, in both the pre- and post-surveys, as shown in Fig. 1, that they "strongly agree" with the following statement: "I am confident in teaching social studies topics in my grade level." It is assumed that the singular "strongly disagree" response was from the participant that is a university professor of future educators and, therefore, may be less confident in teaching social studies topics. When asked about their confidence in teaching engineering topics at their grade level, however, all participants reported some level of disagreement with the statement. Upon completing the professional learning workshop, five participants indicated that they now either slightly agreed ($n = 2$) or agreed ($n = 3$) with the statement "I am confident in teaching engineering topics in my grade level", as seen in Fig. 2.

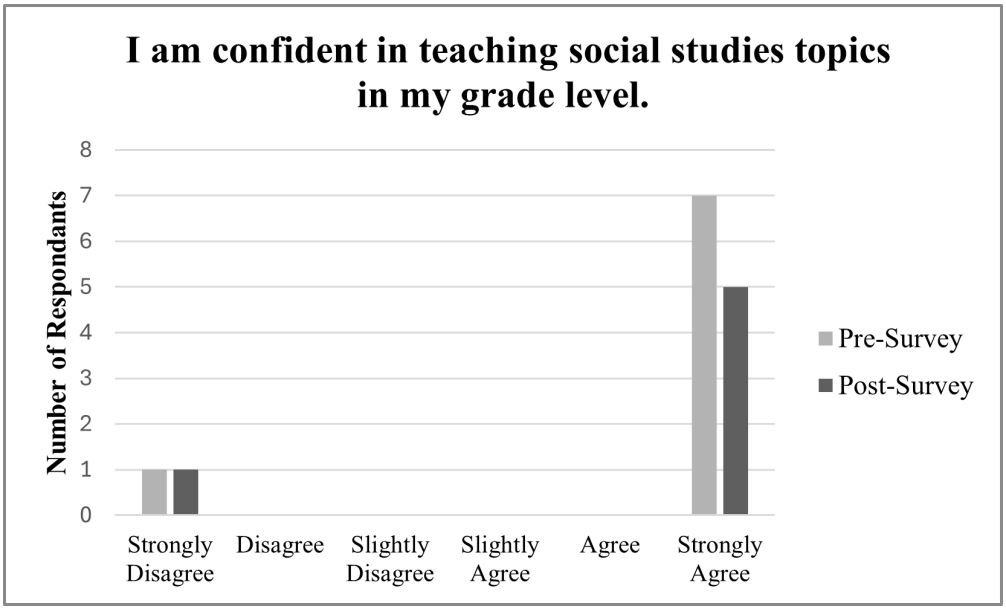

Figure 1: Responses Indicating Participants' Confidence in Teaching Social Studies Topics at Their Grade Level

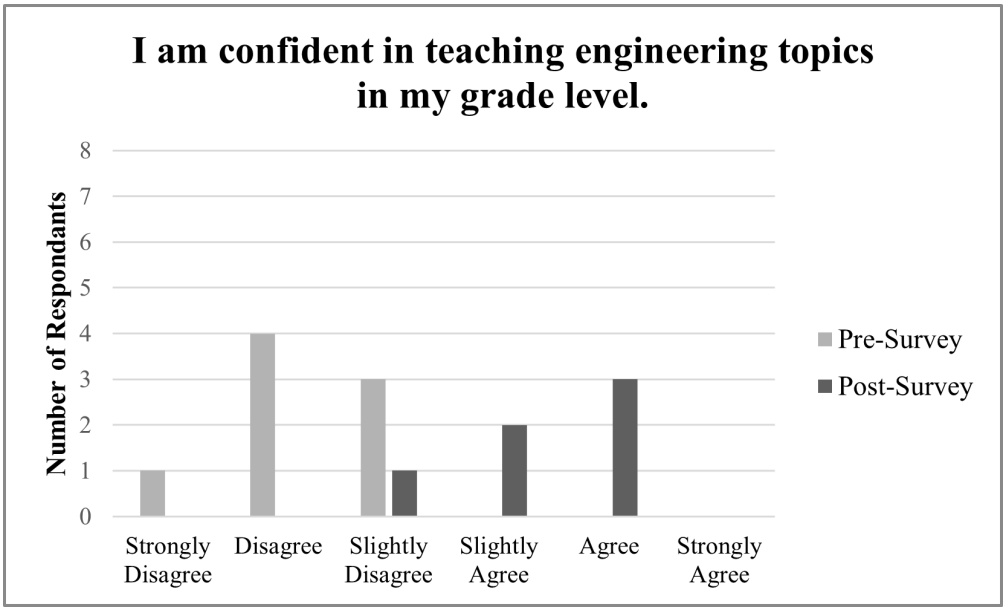

Figure 2: Responses Indicating Participants' Confidence in Teaching Engineering Topics at Their Grade Level

Before completing the workshop events, seven of the eight teachers indicated some level of disagreement with the statement "I am knowledgeable in how engineering concepts are applied in my content area of courses," while one respondent indicated slight agreement. Upon completing the workshop, all six respondents indicated that they now either slightly agree (n = 2) or agree (n

= 4) that they are knowledgeable in the application of engineering concepts in their content area, as seen in Fig. 3.

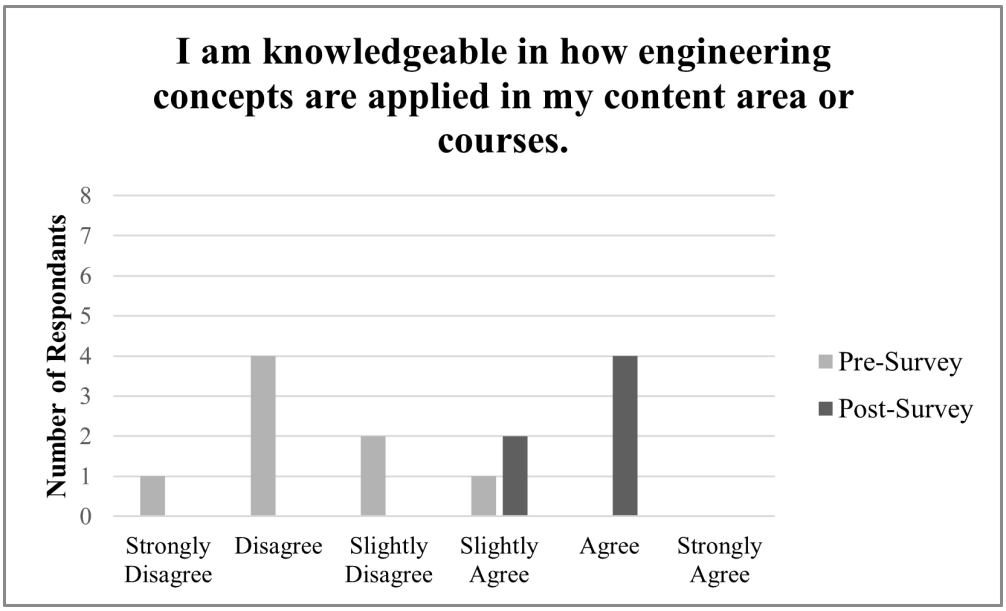

Figure 3: Responses Indicating Participants' Knowledge Level with the Application of Engineering Concepts in Their Content Area

In the pre-survey, teachers reported varying levels of agreement regarding their understanding of how systems engineering applies to voting systems. As shown in Fig. 4, five teachers indicated a level of disagreement with the statement, whereas three teachers indicated a level of agreement. However, during the post-survey, upon completing the workshop, all respondents indicated that they either agreed (n = 5) or strongly agreed (n = 1) with the statement that they understand the application of systems engineering in voting systems. Similarly, Fig. 5 displays a range of responses to the statement "I have an understanding of how systems engineering principles can be applied to solve problems across various situations" in the pre-survey. In the post-survey responses, all respondents indicated a general level of agreement with the statement after having completed the professional learning workshop.

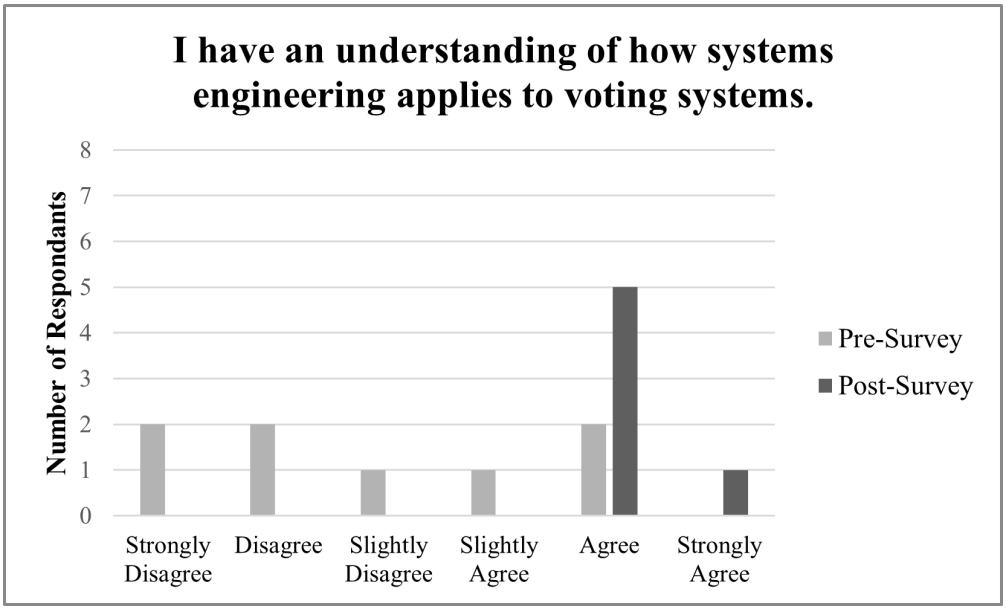

Figure 4: Responses Indicating Participants' Understanding of the Application of Systems Engineering to Voting Systems

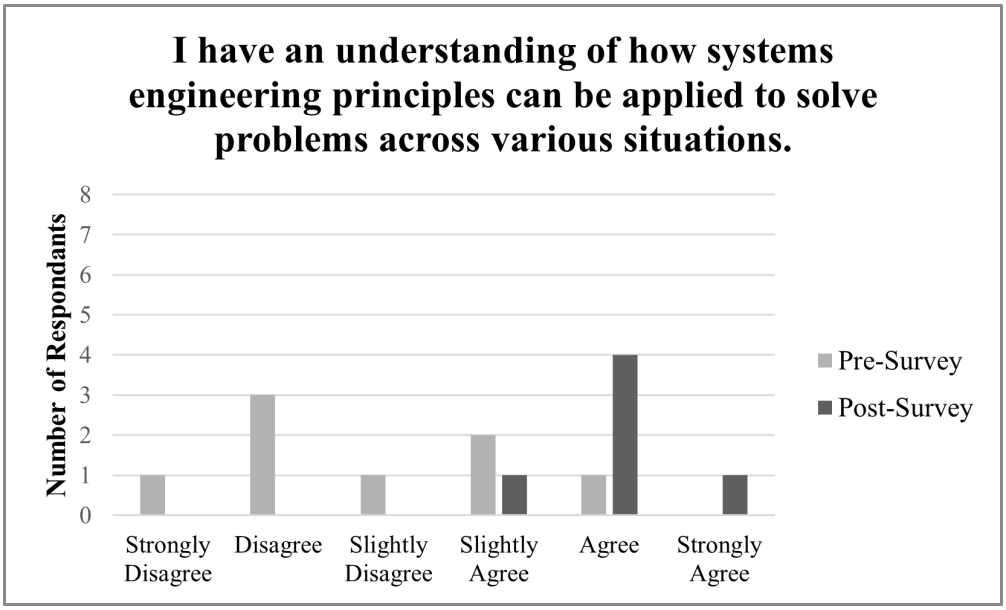

Figure 5: Responses Indicating Participants' Understanding of the Application of Systems Engineering Principles to Solve Problems Across Various Situations

Both surveys concluded with questions about the teachers' confidence and preparedness in teaching the EDI-inspired resources that served as the basis for the workshop. As seen in Fig. 6 and Fig. 7, the pre-surveys included a variety of responses for both confidence level and preparedness, as teachers were only provided with a brief description of EDI's work and

industrial and systems engineering before completing the survey. In contrast, the post-survey results indicated a general level of agreement with both statements across all respondents.

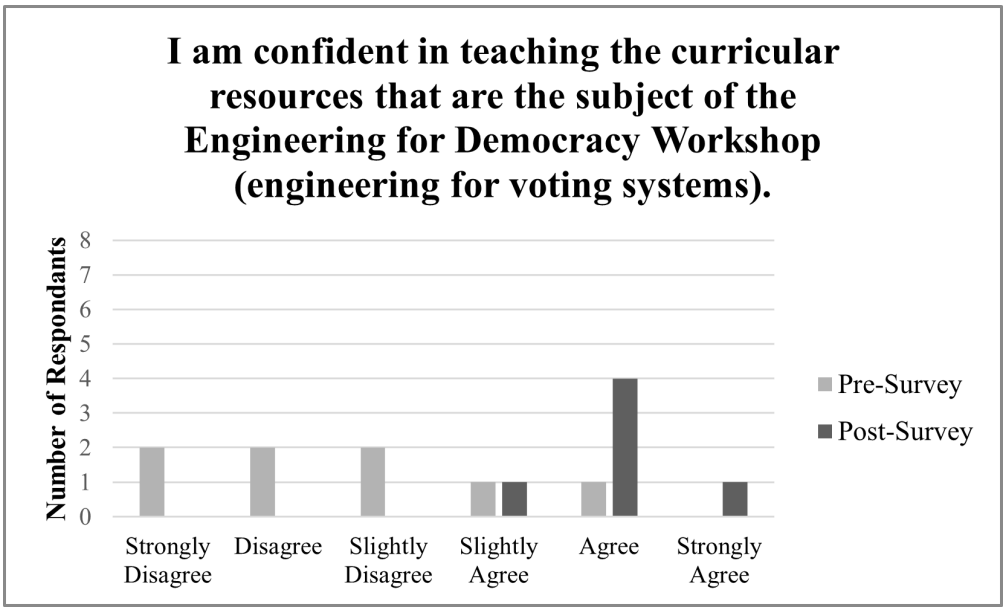

Figure 6: Responses Indicating Participants' Confidence in Teaching the Resources Taught During the Engineering for Democracy Workshop

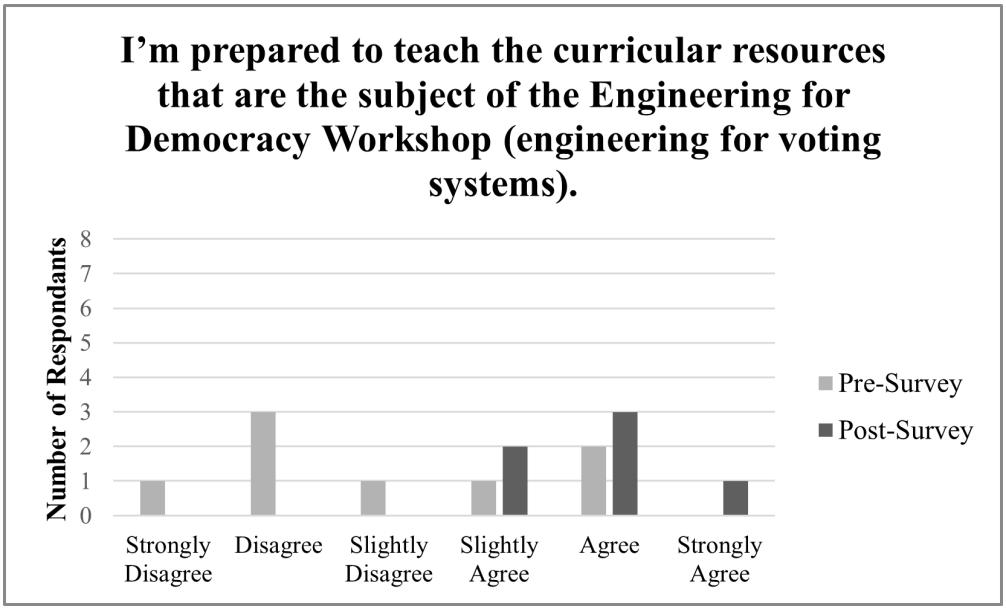

Figure 7: Responses Indicating Participants' Preparedness in Teaching the Resources Taught During the Engineering for Democracy Workshop

Discussion

The collaboration between EDI, GEMS-Net, and the Navy STEM Coalition resulted in the development of a K-12 educational module that introduces students to the application of industrial and systems engineering for improving voting systems and positively impacting the democratic process. Although middle and high school teachers are traditionally confined to teaching one area of study, the professional development workshop hosted by EDI, GEMS-Net, and the Navy STEM Coalition aimed to introduce specialized educators in social studies and civics to STEM disciplines and examine the relationships between their typical subject and other cross-disciplinary fields. The survey results collected from participating social studies teachers indicated that, through exposure and opportunities to learn, educators who are traditionally unfamiliar and uncomfortable with teaching STEM and engineering-related subjects can gain the confidence and tools necessary to teach STEM topics to their students. These findings indicate the importance of a cross-disciplinary education system and of cross-trained educators to draw connections between subjects for students.

Although the number of participating educators was limited, the survey results show an overall increase in teacher confidence and understanding after completing the workshop. Teachers expressed a greater understanding of industrial and systems engineering, as well as its relationship to elections and overall relevance to everyday occurrences in society. Future applications of this work should further explore cross-disciplinary education opportunities for teachers that combine applications of STEM and humanities teachings. Additional studies should also be conducted to understand students' comprehension of cross-disciplinary topics when shared through mediums like this module by teachers who traditionally teach one subject area.

Conclusion

The survey results collected before and after the workshop indicate that exposure to this module provides social studies teachers with an increased level of confidence and understanding in teaching applications of civics-related work with links to STEM teachings. By linking traditionally unrelated subjects through common applications, students have the opportunity to be exposed to a variety of occupations and gain a deeper understanding of subjects as they are continuously reinforced across classes. However, before students can have the opportunity to receive a cross-disciplinary education, educators must first be exposed to these cross-disciplinary studies and applications that combine STEM and humanities subjects. This module has already been used in social studies classrooms and presented at national conferences for engineers and educators, who are then able to return to their school districts and utilize these materials with their students. EDI, GEMS-Net and the Navy STEM Coalition plan to host additional workshops in the future to continue sharing this work with other social studies teachers and expand their understanding of STEM-applications in civics. The teachings of the module aim to provide a cross-disciplinary education for both students and teachers by showcasing a real-world application of industrial and systems engineering and its connection to voting and the democratic process, while supporting teachers who can inspire their students to improve the world through engineering and civic participation.

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Appendix: Pre-Survey Questions

*Note: Question also included in the Post-Survey are indicated with **

*Q1 - Participant Number

Q2 - School District

Q3 - What level do you currently teach at?

- Middle
- High
- Both
- Other (please specify)

Q4 - What grade(s) do you currently teach?

- 6
- 7
- 8
- 9
- 10
- 11
- 12
- Other (please specify)

Q5 - What content area or courses do you currently teach?

- Social Studies
- History
- Civics
- Government
- AP Courses (please specify)
- Other (please specify)

Q6 - What, if any, experience do you have in STEM fields or teaching STEM subjects?

*Q7 - Please select how strongly you agree or disagree with the following statements:

(Strongly Disagree, Disagree, Slightly Disagree, Slightly Agree, Agree, and Strongly Agree)

1. I am confident in teaching social studies topics in my grade level.
2. I am confident in teaching engineering topics in my grade level.
3. I am knowledgeable in how engineering concepts are applied in my content area or courses.
4. I have an understanding of how systems engineering applies to voting systems.

5. I have an understanding of how systems engineering principles can be applied to solve problems across various situations.
6. I am confident in teaching the curricular resources that are the subject of the Engineering for Democracy Workshop (engineering for voting systems).
7. I'm prepared to teach the curricular resources that are the subject of the Engineering for Democracy Workshop (engineering for voting systems).