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Teaching Materials Science and Engineering (MSE) in the Pre-College Classroom as a Vehicle for NGSS Implementation

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ABSTRACT

Adoption of Materials Science and Engineering (MSE) into the pre-college classroom is an ideal strategy for addressing Next Generation Science Standards (NGSS), specifically the Science and Engineering Practices. MSE offers core science and engineering topics that can be incorporated into existing Science, Technology, Engineering, and Mathematic (STEM) curricula through teaching modules. Using MSE as a teaching vehicle, the Center for Research on Interface Structures and Phenomena (CRISP) conducted a series of small-scale studies of its teacher professional development workshops and a student summer program, along with related teaching modules, in an effort to measure the contribution MSE has on students and K-12 STEM educators. Based on participant survey feedback, CRISP found improvement in students' MSE knowledge, interests, and career goals. For teachers, in addition to improving their MSE knowledge, they also increased their comfort and confidence in teaching MSE concepts in their classroom. These results provide evidence for the use of MSE modules as productive teaching tools for NGSS Science and Engineering Practices, as well as producing workforce-competitive STEM students.

INTRODUCTION

The nation's competitive development and future economic and social growth depend on the innovation, creativity and scientific and mathematical literacy of our future science and engineering students [1]. Despite incremental progress in certain aspects of education, American students continue to fall below average on mathematical and scientific skills needed to succeed in a complex global economy. In order to address these knowledge and skill deficits and overcome prior shortcomings, the National Science Education Standards were recently reevaluated and improved in light of current scientific pedagogy to better prepare future scientists and engineers. The National Research Council, National Science Teachers Association, American Association for the Advancement of Science, and Achieve have all contributed to the development of these NGSS. These standards highlight the skills and content needed to enhance K-12 students' understanding of science and the 21st-century workplace. The NGSS focus is to improve science education through three-dimensional learning and instruction which include Science and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas [2]. MSE provides a unique opportunity to address the principles of the scientific method and engineering

design through Science and Engineering Practices and teach fundamental 21st century collaboration and teamwork skills. By incorporating the NGSS into science classrooms, students learn core STEM content and concepts, as well as the related knowledge and skills they need to prepare for diverse and high-need careers [3,4].

A primary obstacle to implementing MSE in a pre-college classroom is a lack of space in the curriculum to dedicate time solely to MSE. Most high schools follow the standard core class model of biology, chemistry, and physics. A specific set of curriculum content and experiences are specified at the district level, leaving no designated class time for MSE. This lack of understanding for and exposure to MSE in early classroom experiences creates a significant problem for future workforce-competitive STEM students, as current growth in technology continues at exponential rates. Society depends on advances in STEM technologies, and early exposure in the pre-college classroom is necessary for future scientists and engineers to continue to drive that progress.

Instead of offering a full course on MSE, modules and isolated classroom experiences can be used within core subjects to expose students to MSE and implement the wide-scope of the NGSS. MSE is interdisciplinary. It covers a broad range of topics including biology, physical science, and engineering and touches on all of the core science content areas of the NGSS. Furthermore, MSE goes beyond core science ideas and includes broader impacts such as social responsibility, environmental implications, and citizenship. These broader impacts of MSE are outlined in the NGSS. In addition, MSE can be used to further students' development of research and engineering design skills (NGSS' Science and Engineering Practices). Given the dynamic nature of CRISP teaching modules, students receive a complete three-dimensional learning experience that benefits teachers' needs, aligns their curriculum with state and national science standards, and serves students' needs to develop as capable and competitive scientists and engineers in our society.

Use of CRISP modules provides educators the opportunity to address the NGSS standards in their core classrooms. CRISP module topics range from electronic materials to bioscience with applications to K-12 for both public outreach and classroom experiences. The overarching goal of CRISP Education and Outreach is to establish programming and resources to address the need for more creative, innovative, and effective means of teaching the 21st-Century Learning skills and the NGSS. This programming is informed by partnerships with local industry and academia, and content is developed based on their direct recommendations of the knowledge and skills they are looking for in employees. Education and Outreach programming is formally developed by the Professional Learning Community (CRISP Collaborative Science for All), which is composed of STEM educators and professionals. These outreach programs specifically target STEM professionals, educators, K-12 students, undergraduates, graduate students, post-docs, and the general public within under-served, demographically diverse school districts. These programs are completed under the MRSEC Initiative for Multidisciplinary Education and Research and MRSEC Initiative for STEM Education [2,3].

The focus of this paper will be on selected programs from CRISP's professional development (PD) for educators and summer classes for students, all of which have been enhanced by teaching modules developed by CRISP research teams. Modules utilize MSE in the context of the core Science and Engineering Practices already taught in public school classrooms and directly address skills and content outlined in 21st-Century Learning and NGSS.

METHODS

The overarching goal for the research project was to utilize an interdisciplinary, cross-cutting field of study (i.e., MSE) to effectively equip pre-college students with the critically identified 21st-Century Learning Skills and NGSS knowledge and practices. MSE was connected with the standard core science and engineering topics already taught in the pre-college classroom in the form of teaching modules. Three CRISP programs focused on MSE are included in this paper - two teacher PD events and one summer course for students - along with the related teaching modules. These CRISP programs/modules were developed and further refined using survey data from participants.

Initial programming efforts began in 2013 with the development of the Materials & Manufacturing Summer Teachers' Institute as PD for K-12 STEM teachers. This program was a three-day, manufacturing-focused workshop series in which teachers heard from industry professionals (New Haven Manufacturers Association) and engaged in hands-on activities with manufacturing processes. The third day of the workshop participants developed NGSS-aligned modules focusing on MSE-related topics [6]. These modules were created based on the knowledge and experience gained throughout the workshop; the modules include many of the skills sought after by manufacturing employers. These modules were then developed into hands-on activities that educators could bring back to their classrooms. One of the NGSS-aligned activities developed was the "Mouse Trap Catapult*"* in which students are given materials and required to design, build, and test a catapult [7]. Due to its success, CRISP has repeated this summer institute for the past four years.

Also in 2013, CRISP facilitated a pre-college course on MSE for high school students called Summer Scholars Program. This program was a week-long summer STEM course that featured teaching modules to prepare academically promising students for success in college and to strengthen their ability to pursue science majors and careers. The program provided an intensive, hands-on science curriculum that emphasized discovery, critical thinking, and problem solving and covered topics including biotechnology, materials science, and engineering. One of the CRISP developed modules used in this course is "Aerogels" which engages students in learning about the unique properties and real-world environmental applications of aerogel materials [9]. This program has continued on an annual basis as well.

CRISP recently created a workshop, focuses on biotechnology and MSE, based around its "Should We Edit the Genome?" module. This one-day workshop for K-12 STEM teachers was composed of a forum on editing the genome, an introduction to the NGSS-aligned synthetic biology modules, a presentation from Southern Connecticut State University's iGEM (International Genetically Engineered Machine) Team [5], and a tour of a synthetic biology laboratory. Presenters at the workshop were from varied academic backgrounds, including biology, physics, computer science, and philosophy. At this CRISP event, teachers discussed in small groups the social and ethical implications of synthetic biology, as well as how to bring this topic into their classrooms to address the NGSS, specifically the engineering and design aspects and state science curriculum.

RESULTS AND DISCUSSION

Highlights of the progression made by teachers and students as a result of CRISP programs are provided here. The impact on student participants' development of 21st-century learning and knowledge skills and changes in their MSE knowledge, interests, and career goals were assessed.

For teacher participants, in addition to assessing changes in their MSE knowledge, adjustments to their comfort and confidence in teaching MSE concepts were also measured. Survey questions were a combination of scaled- and free-response questions that were delivered in a pre/post design or retrospectively following the conclusion of the program. In the cases where programs have occurred for multiple years (Materials & Manufacturing Summer Teachers Institute and Summer Scholars Program), data are combined across program years and treated as one large dataset.

Materials & Manufacturing Summer Teachers Institute (2013-2016)

Data across four years of the Materials & Manufacturing Summer Teachers Institute workshop series (*N*=98) show that teachers gained the most in the following scaled-response survey questions as a result of the program:

- *"I have a clear understanding of how engineers contribute to product development."*
- *"I have a clear understanding of specifically how the CRISP program can assist me with my teaching."*

Combining these results with the free-response survey questions shows that teachers had a real-life learning experience that they intended to bring back to their classrooms and share with their students. After the program teachers reported feeling more energized and confident in their ability to teach MSE topics, specifically because they received lesson plan ideas and access to resources to implement hands-on activities as a result of making connections with the New Haven Manufacturers Association and CRISP. They also enjoyed learning about local jobs available to their students and the STEM skills required of their students to compete for those jobs (e.g., math, chemistry, and physics). One teacher wrote, "*Understanding connections between the type of material and process used to manufacture is important. Problem-solving is essential for strong workers and so problem-solving needs to be included in the curriculum. Cross-curricula (science and math) is also needed.*" In this way, teachers saw the need and relevance of MSE for preparing their students to be workforce competitive.

Summer Scholars Program (2013-2016)

High school students have benefited over the past four years from the Summer Scholars Program (*N*=94), with the largest gains in the following survey questions:

- *"I understand the connection between the discipline of Materials Science and the development of everyday products."*
- *"I have a good understanding of what the topic of 'Materials Science and Engineering' is all about."*
- *"I have a good understanding of careers involving materials science and nanotechnology/biotechnology."*

Overall, the Scholars students learned about many aspects of materials science, engineering, and how these fields lead to the development of everyday products. Based on students' free-response question answers, they were most interested in the demonstrations and hands-on activities throughout the program. They also benefited from discussions on pursuing graduate-level education and careers in these fields. One students said, "*I hoped to learn more about what*

Biomedical Engineering is and how I can pursue a career in BME in my future. I had educational lectures and amazing demonstrations that greatly helped me learn about my field." In this way, students benefited not only from changes in content knowledge related to the program topic, but also received advice for pursuing a career path in a STEM field.

"Should We Edit the Genome?" Workshop (2016)

Eighteen teachers participated in the "Should We Edit the Genome?" PD event. They reported on their knowledge and feelings in relation to synthetic biology and its impact on daily life, as well as connections to implementing these topics in their classrooms. On all surveyed topics, teachers reported being significantly more knowledgeable after the workshop than before - they learned facts, applications, societal aspects, and other viewpoints as related to synthetic biology. One teacher commented, "*I teach biology and this directly relates to my NGSS high school objectives relating to STEM from the biological side of its application*." They also became more motivated to read news stories about synthetic biology and found it especially valuable to receive materials they could bring back to their classrooms. Teachers felt the workshop helped them overcome concerns and obstacles they faced in the classroom by showing them how to manage difficult topics, keep discussions orderly, express minority viewpoints, and address fear and uncertainty related to genetically-modified organisms. Overall, teachers found the workshop was rich in learning about biotechnology and its applications, and could be directly incorporated into their current science curriculum.

CONCLUSIONS

Overall, this project provides evidence that MSE has the potential to effectively teach the NGSS Science and Engineering Practices necessary to prepare and train students to become well-educated, scientifically literate, and socially diverse for the complex demands of the 21st century workplace. These CRISP programs (and related modules) are a few of many MSE activities that align with the NGSS and 21st-Century Learning and can be used to enhance K-12 science education. CRISP has developed other teacher PD and student programs to this end - for example, an immersive summer research experience where teachers and students work as part of interdisciplinary teams on a research project under the guidance of university faculty and researchers, numerous one-day PD workshops for teachers covering such topics as modeling and teaching science to special education students, and outreach activities including faculty-delivered public lectures and participation in the city science fair with family science nights [8].

This Education and Outreach programming is very effective in addressing the three dimensional learning aspects of NGSS, providing participants the opportunity to learn about the process of science and engineering through first-hand engagement in team-based interdisciplinary research. The relevance and significance of these experiences can be seen in that 85% of CRISP-impacted teachers have already implemented some aspect of a CRISP program/resource in their classroom. Additionally, students across programs report becoming more informed and excited about MSE and their desired career paths. Career preparation and development of STEM-related skills through MSE drive CRISP programming and address the current needs of academia and industry.

Building on the success of the three featured programs in this paper, CRISP plans to develop a biotechnology-focused summer teachers institute focused on providing K-12 science teachers with insights into the skills and competencies required of students to gain future employment in

the biotechnology industry. It will not only serve as a bridge joining educational institutions to local Connecticut biotechnology industries, but will also connect workshop content and training practices to the NGSS, further enhancing the education and awareness of science teachers and K-12 students.

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At the date this manuscript was written, URLs or links referenced herein were deemed to be useful supplementary material to this manuscript. Neither the author nor the Materials Research Society warrants or assumes liability for the content or availability of URLs referenced in this manuscript.

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