Early Introduction of STEM Through Sustainable Engineering

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Abstract To educate the next generation of scientists and engineers, it is important to cultivate critical thinking and problem-solving skills within the context of sustainability. *Eva the Engineer*, an elective course developed by the University of Wisconsin–Madison engineering students, uses sustainability-focused civil engineering lessons to (1) introduce sustainable engineering practices at the middle school level and (2) encourage young women to pursue science, technology, engineering, and mathematics (STEM). *Eva the Engineer* students explore the environmental, social, and economic impacts of the infrastructure around them and practice sustainable engineering decision-making with hands-on activities. The primary topics of discussion are infrastructure design, water resources, and waste management. As civil engineering is a central theme of the course, the primary examples of sustainable engineering involve the energy and water reductions using recycled materials in construction applications. For example, students make concrete stepping-stones with recycled materials and calculate energy, water, and greenhouse gas emission savings achieved when recycled materials replace virgin aggregate in concrete. Later, a field trip to a concrete production facility, a landfill, a recycling facility, and a wastewater treatment facility demonstrate the practical implications of construction and waste generation. By the end of the program, students exhibit an understanding of contemporary environmental challenges, basic engineering principles, and the benefits of recycled materials in engineering applications. Program survey results also illustrate a ubiquitous increase in self-confidence in STEM capabilities among students. Engaging the next generation of engineers and scientists in a discussion of present issues is proving to be beneficial for all involved.

Keywords Recycled materials · Education · Sustainability · Civil engineering

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1 Introduction

A study published in Science magazine reported children at the age of 5 are equally as likely to assume a person of their own gender when given the description "A person in my office is really, really smart—they solve problems faster and better than anyone else." By the age of 6 and 7, however, girls are 20–30% less likely than as their male counterparts to assume the person being talked about is of their own gender [1]. It is not clearly understood exactly what causes this early and dramatic shift, but this pattern continues into adulthood. According to the 2009 Census, women hold 48% of total jobs in the United States, but only 24% of all science, technology, engineering, and mathematics (STEM) jobs. The lowest percentages of women are found in engineering fields, only 14% of engineers in the United States are female [2]. There are clear obstacles for women to enter STEM fields, and this has a negative impact on those fields.

In learning of the *Science* magazine article and observing the gender discrepancy in the engineering courses at the University of Wisconsin–Madison, the authors were inspired to visit local middle schools and encourage young women to consider pursuing STEM. The authors developed a program called *Eva the Engineer* to teach young women in Madison area middle schools. The title of the program, *Eva the Engineer,* was intended to personify a female engineer of any cultural background such that she is approachable and relatable to all students. Additionally, the alliteration of *Eva the Engineer* continues with the program objectives: to educate, excite, and encourage young women to pursue careers in sustainability and civil engineering. Each lesson has a technical focus and utilizes hands-on activities to inspire critical thinking and problem-solving. The *Eva the Engineer* course curriculum uses hands-on activities to teach lessons on sustainability, the principles of civil engineering, and women in STEM. Life cycle assessments, water use and water treatment, concrete materials, and the use of recycled materials in construction applications are just a few of the sustainability-focused engineering principles developed to engage and inspire young female students. This report illustrates the curriculum development process and presents the results of the *Eva the Engineer* program using pre- and post-program surveys.

2 Program Development and Implementation

2.1 Program Development

All lessons created for the program were original and drew upon fundamental engineering concepts such as force design, product sustainability, and project planning. The mission of the program is to "Educate, Excite and Encourage young women to pursue careers in STEM," with a focus on sustainability and civil engineering.

Learning objectives and lesson materials were developed within the scope of the mission.

2.2 Curriculum Outline

The course content was organized and developed in three units: professionalism, sustainability, and infrastructure. The units were selected to teach the principles of civil engineering, sustainability, and women in STEM. Each unit is described in some detail in this section, and a summary curriculum map is presented in Table 1.

Sustainability Unit. In the sustainability unit, examples and products from civil engineering and from daily life are used to demonstrate the environmental, social, and economic components of sustainability. Students engage with contemporary environmental issues surrounding water usage, municipal solid waste, and construction and demolition waste. Students conduct qualitative and simple quantitative life cycle assessments of a shoe, bottled and tap water, and recycled materials in construction applications. Students learn to define sustainability and critically consider the impacts of personal decisions and the impacts of engineering decision-making in infrastructure. The sustainability unit is identified as Unit 1 in Table 1.

Professionalism Unit. In the professionalism unit, lessons emphasize the historical impact of women on science and engineering, and how that has translated to the workforce today. Practical applications of the engineering and sustainability concepts are enforced with a field trip experience. The field trip includes tours of a ready-mix concrete facility, a recycling facility, and the county landfill. After the field trip, many students noticed that there no women were encountered throughout the day at any of the visited sites. This important observation is addressed in the course with examples of women in STEM history and local women in STEM. Homework for this course involves reading and interacting with the book *Women in Science: 50 Fearless Pioneers Who Changed the World* to illustrate the crucial role of women in STEM history [3]. In the final lesson of the program, a panel of women in STEM careers from the Madison area is assembled to speak with the class and answer questions. In this forum, the students interact with and relate to these women. The professionalism unit is identified as Unit 2 in Table 1.

Infrastructure Unit. In the infrastructure unit, lessons focus on the design and materials of modern infrastructure. Simple structural design is presented using static force balance and force body diagrams. Interactive team projects require students to build small structures with limited materials and time, exercising static force concepts and their problem-solving abilities. Team projects encourage participation and engage the students in a small-group discussion regarding the lesson material. In this unit, the use and composition of concrete are a primary focus because concrete is the most prevalently used material in the construction industry. Students learn the different ingredients of concrete and the purpose of each component using a cookie analogy. The students also have the opportunity to work with concrete in both its

Table 1 Curriculum map

Unit*	Objective	Content	Assessment
2	Introduce the course	Women in STEM statistics, class core concepts [2]	Introductory survey
2	Breadth of STEM fields	Breadth of STEM fields, Responsibilities of engineers [4]	Women in STEM worksheet
1	Waste generation and treatment	Waste sources, Solid waste treatment [5]	Landfill in a bottle activity
3	Concrete uses and components	Concrete history, Concrete impacts, recycled materials	Analogy of concrete mix design and cookies
2	Occupations in civil engineering	Field trip to wastewater treatment plant, concrete production facility, landfill, recycling facility	
1	Global water usage, LCAs	Global water usage, qualitative LCA comparison [6, 7]	Personal water usage sheet
1	Construction waste	Construction waste generation and disposal [8, 9]	Decomposition rate survey
1	Practice LCA	Product sustainability, Triple bottom line [10]	LCA of a Boot worksheet
3	Infrastructure	Infrastructure definition and importance [11, 12]	UCLA water main case study
3	Mechanics, infrastructure	Compressive and tensile forces, static force equilibrium [13]	Popsicle bridge design and creation
3	Mechanics, infrastructure	Engineering decision-making, material use [13]	Newspaper chair design and creation
3	Experience with concrete	Components of concrete, recycled materials	Concrete stepping stones
1	Recycled materials in construction	Recycled concrete, Acid–base chemistry	Water and concrete chemistry experiment
2	Celebrate women in STEM	Accomplishments of women in STEM history [3]	Women in STEM Bingo
2	Interact with professional STEM women	Career panel of local professional women in STEM	Exit survey

*Unit 1: Professionalism; Unit 2: Sustainability; Unit 3: Infrastructure

viscous and solid phases, an opportunity not available to most middle school students. The infrastructure unit is identified as Unit 3 in Table 1.

2.3 Lesson Instruction

Eva the Engineer has been taught three times at three different schools in the Madison area: Badger Rock Middle School, Toki Middle School, and Verona Badger Ridge Middle School. For the first two iterations of the program, the elective class was taught once a week for an hour for one academic quarter. In the third and most recent generation of the program, the curriculum was expanded to 15-hour-long lessons taught weekly as an after-school program.

The lessons are generally structured to include a 10-minute lecture introducing the technical concept followed by a hands-on activity. The instructors maintain student engagement during the lecture by establishing an open discussion of the material, and by posing questions to incite critical thinking, per the Socratic Method. The hands-on activities allow the students to practice problem-solving, communication, teamwork, and understanding of the technical concepts.

3 Results

Eva the Engineer has proven to be beneficial for the middle school students, the instructors, and the partners from industry. The students enrolled in the course are afforded an opportunity to explore engineering in an approachable and engaging environment. While there are local day programs for young women in science and technology, bringing the program directly to the classroom made the opportunity accessible for students of all socioeconomic backgrounds. By providing students with role models they could relate to, it was conveyed that people of all identities and backgrounds are capable of succeeding in STEM fields.

To quantify the impact of the program and to solicit feedback from the students, pre- and post-program surveys are administered. The surveys first ask the students to evaluate their perceptions of their own abilities on a scale of 1–10 (1 = incapable, 10 = very capable) in nine categories pertinent to STEM careers: problem-solving, math, science, writing, confidence, social, leadership, creativity and hard-working. During the first and last sessions of the program, the students are given a survey to evaluate their perceptions of their own abilities in categories pertinent to STEM careers. Most notably, the female students rate themselves higher in all nine categories at the end of the program (Fig. 1). Figure 1 demonstrates that, following the lessons and activities, the students feel more certain in their own STEM capabilities. This observed tendency is consistent for each of the three schools.

A control group of male students was surveyed using the same method in order to compare to the pre-program survey administered to the female students (Fig. 2).

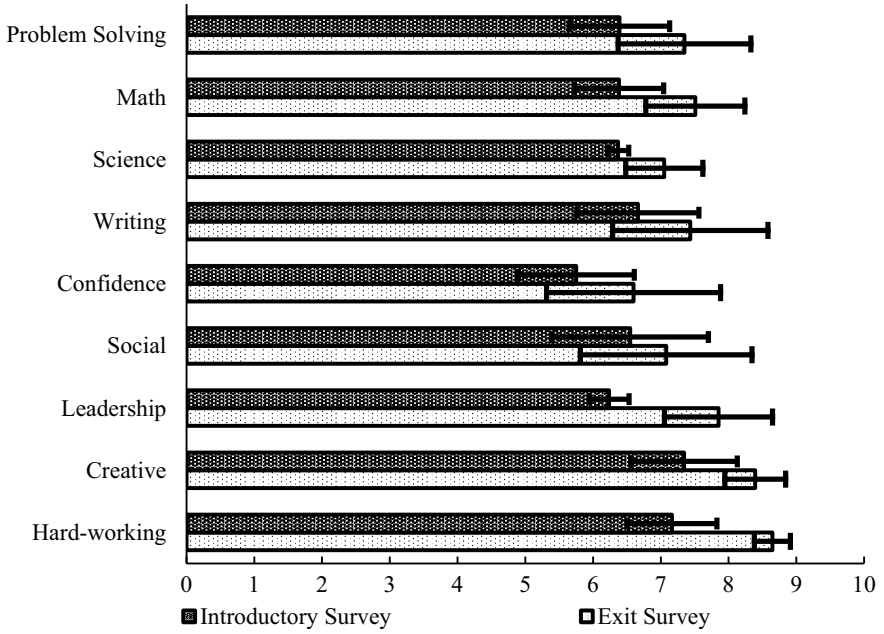

Fig. 1 Average response and standard deviation of 43 female students when asked to rate themselves on a scale of 1–10 in the listed categories

Different sample sizes limit the conclusiveness of this data; however, the present data illustrate some a difference in perception of capabilities dependent upon gender. Female students rate themselves highest in writing capabilities, creativity, and work ethic, and rate themselves lowest in math, science, leadership, and problem-solving (Fig. 2). Male students rate themselves highest in social skills, leadership, problem-solving, confidence, and work ethic, and lowest in writing and creativity (Fig. 2).

In addition to the self-evaluation survey, the end of the program survey includes a feedback questionnaire. The students are asked to recall the most interesting thing they learned in *Eva the Engineer*, and their responses include:

1. "How many different engineering jobs there are."
2. "That engineering is more than one thing."
3. "How big of an impact it is to drink bottled water (social and economic impact)."
4. "There is a degree for exercise."

The responses of the students indicate that the content and activities of the program achieve the mission to educate, excite, and encourage young women in STEM fields. The responses of the first and second students tell communicate that the students are introduced to potential careers that they did not yet know. The third student commented that the most interesting thing that she learned was the relative impacts of drinking bottled water instead of tap water, referring to the social and economic impacts; she is recalling information from the second lesson, demonstrating that the

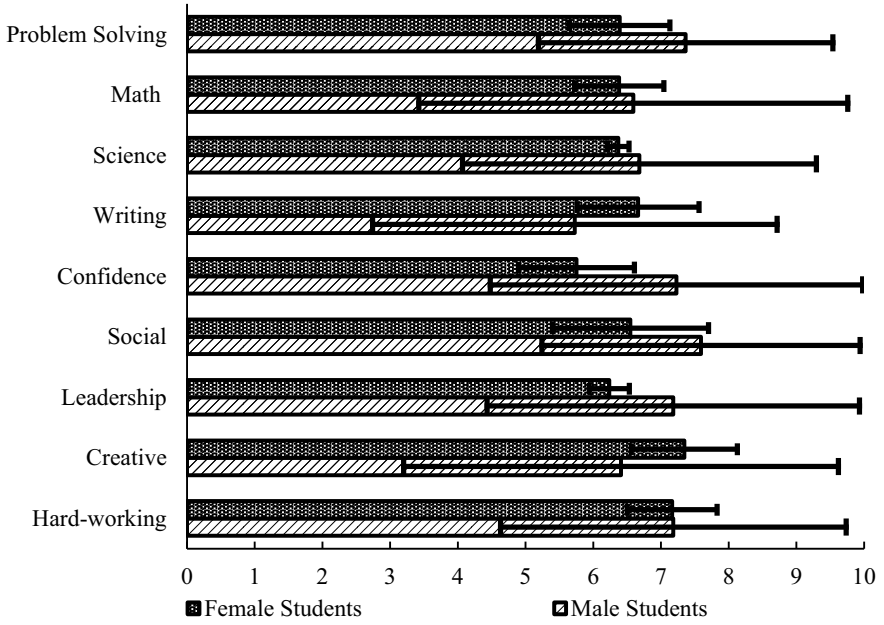

Fig. 2 Average response and standard deviation of student responses when asked to rate themselves on a scale of 1–10 in the listed categories. Note sample sizes: 43 female students, 13 male students

material and activities were impactful and memorable. The fourth student was most interested to learn that there is a college degree for exercise. She is referring to one of the women on the Women in STEM career panel who has a degree in kinesiology. This comment is great feedback because although the student may not have been as interested in civil engineering as a future career, the career panel in the final lesson showed her other STEM opportunities that she found interesting.

4 Conclusions

A program such as *Eva the Engineer* is critical in educating the next generation of female engineers and scientists, engaging them in discussions of contemporary environmental challenges, and instilling fundamental engineering principles. Students leave the STEM program with increased confidence in their abilities related to sustainability and engineering. By presenting examples of successful female engineers of diverse backgrounds and allowing young women to explore the engineering field interactively, students envision themselves succeeding in STEM fields. Having more women in STEM will benefit the industry, as a more diverse workforce will be better equipped to deal with the engineering challenges of the future.

The authors are planning to continue this program in schools within Dane County, Wisconsin and looking to expand the impacts of the program via industry partnerships. Future funding of this program would sponsor the development of a downloadable website package, complete with all program materials, available for university students across the nation to use to teach the program in their communities.

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