Engaging Students in Sustainability Education and Awareness of Green Engineering Design and Careers through a Pre-Engineering Program

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Abstract

A framework for an active learning summer program for middle school students is presented along with survey instruments and pre and post program data regarding student attitudes and awareness of sustainable design issues and career motivation in the field. This summer program was designed to attract students, especially from underrepresented groups, into early motivating experiences in the engineering fields and to increase their awareness of concepts and careers in renewable energy, and green engineering design principles and technologies. Twenty-four middle school students from a low social economic school district were provided the opportunity to experience many state-of-the-art engineering technologies at the university's school of engineering and to learn from a diverse group of knowledgeable mentoring faculty. In the week - long program, students were involved in hands-on engineering and renewable energy activities appropriate to their age and knowledge. Topics covered included: the engineering design process, CAD solid modeling, 3D printing and water jet cutting, hands-on assembly, renewable energy resources for homes, sustainable site selection, and water efficiency principles. Using project-based learning, student teams participated as designers of their own green home models by integrating their learning of renewable energy use, conservation practices, and appropriate design and material selection. Pre and post surveys revealed increases in student awareness of general engineering and renewable energy concepts as well as increased interest in pursuing engineering careers.

Introduction

This study revolves around the topics of *sustainability education* as well as *green design*. It is therefore appropriate to first begin with definitions of each term. According to UNESCO, Education for Sustainable Development (sustainability education) involves the inclusion of "key sustainable development issues into teaching and learning such as climate change, disaster risk reduction, biodiversity, poverty reduction, and sustainable consumption."[1] Education about green design and building is defined by the US Environmental Protection Agency as "the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction." [2] Therefore, sustainability education has to do with teaching about using less energy and fewer resources, recycling, about buying locally and organically, designing and building with environmentally mindful or "green" approaches. Further, it is about guiding students of all ages to what Smith calls "changes in attitudes, beliefs, and dispositions related to what may be necessary to forge more sustainable societies." [3] Organizations such as the International Union for the Conservation of Nature (IUCN) and United Nations Educational, Scientific and Cultural Organization (UNESCO) have indicated the importance of environmental and sustainability education[4] to overcome our global community's alarming environmental problems. In a related movement in environmental education, in 1972, the United Nations Conference on the Human Environment proclaimed environmental education as essential for citizens of all ages in order to provide a basis for both enlightenment and "responsible conduct by individuals, enterprises and communities in protecting and improving the environment in its full human dimension"[5].

Research in K-12 sustainability education in engineering

In the last few decades, there has been a renewed interest and value recognition of environmental and sustainable learning. Particularly relevant to this discussion is Pavlova's[6] call for policy formulation, teaching and learning for sustainability education and teacher training as three essential areas of challenge in the inclusion of sustainability education in technology. Education researchers find that K-12 sustainability education is not only about increasing content knowledge but that results are influenced by instructional practices that are dynamic and action-oriented and affect engagement not only in science courses but also in social sciences and even in art. [7, 8, 9] Church and Skelton report on a survey study involving more than one thousand K-12 teachers and report that over 66% have employed a particular kind of sustainability curriculum in which sustainability was used as an interdisciplinary unit, a context for teaching core subjects, or as a stand alone subject. In a related sub-study involving 55 high school teachers, Church and Skelton found that "almost all (96%) of the teachers reported that the lessons taught using the contextual framework of climate change increased their students' critical thinking skills. Most (82%) saw increased engagement in the classroom with this context, and 79% said the units "increased students' belief that they can make a difference on global issues". [10] It is clear that the benefits of carrying out sustainable education are considerable and integrating it with other content areas can result in powerful learning.

Green engineering design in sustainability education and in this study

Green engineering design can be defined as a combination of engineering, science and technology practices with environmentally acceptable methods and principles.[11] Some green engineering design focuses on designing around environmental changes and adopting these environmental changes. Sustainability education can be implemented along with green engineer design with very young students.[12] As stated above, it is important to provide environmental awareness and learning opportunities to younger generations and have them actively involved with green engineering activities. Implementing environmental learning and green engineering together in early stages such as at the middle school level can be crucial for understanding the importance of environmental issues as well as the concepts and possibilities for environmentally friendly design. [13]

This study aims to understand how an intervention program that is based on the integration of sustainability education and green engineering design can impact student learning and career awareness. A summer camp is described as the setting where students learn about potential negative technological impacts upon our environment and how to prevent some of them by applying important green engineering design principles. The culminating design activity encourages the students to utilize green engineering design principles directly [14] by creating a small house model that:

- Is designed using system analysis and integrated environmental impact assessment tools. Students learned system design and implementation around environmental issues.
- Uses materials that improve natural ecosystems while protecting human health and well-being.

- Uses materials that have a long lifecycle and less impact on environmental issues.
- Uses materials and energy that are considered safe.
- Uses reusable materials to minimize depletion of natural resources.
- Uses a design methodology to minimize waste.
- Uses a design based on local geography, aspirations and cultures. The garden and outside of the house is designed with consideration for local culture and matching local vegetation.
- Uses sustainable technology such as solar panels, wind turbines and LEED certified building materials.
- Is designed using a group of students not only to learn about green engineering and environmental issues, but also to actively engage and create their own solutions to some of these problems. Different water collection systems as well as roof designs were innovated by students.

As described above, these middle school students learn green engineering design and new technologies using sustainability education to create a learning structure that will benefit not only them, but will also benefit future engineers and the environment. These activities and result from these activities will be presented in the next sections.

Background

The Ingram School of Engineering (ISOE) at Texas State University was founded in 2007. The undergraduate program offers three ABET accredited engineering degrees in electrical, industrial and manufacturing engineering. ISOE provides a strong educational experience via theory combined with practice in a class/lab atmosphere. Dedicated faculty and staff are directly involved in classes and labs, and each degree program culminates with a senior design or "Capstone" project, which is required for graduation. Capstone projects emphasize project management, technical deliverables, and multidisciplinary effort in team-oriented, long-term projects. As a result of the heavy emphasis on practical, applied, and experiential learning, students who graduate from ISOE are well prepared for careers in all aspects of engineering. The school has more than 800 engineering students. In addition to modern classrooms and computer labs, ISOE has fully equipped labs including a class 1000 Cleanroom, System Modeling and Renewable Technology (SMART) lab, the Center for High Performance Systems (CHiPS), Additive Manufacturing facilities, and Rapid Product Development (RPD) lab. The school of engineering keeps strong ties with the local community. One form of these ties is strong outreach program that is essential for the school and for Texas State University. Outreach programs are deployed in different forms from summer camps to on-campus high school recruitment events and school tours.

The team of faculty involved in the green design summer camp presented in this paper has extensive experience designing successful Science, Technology, Engineering and Mathematics (STEM)-related short and long-term camps for K-16 students. Examples are two National Science Foundation-funded Summer Research Experiences for Undergraduates (REU); these ten-week long residential summer programs included a broad range of scientific and extracurricular activities. Another example includes a two 2-week long Engineering and Art camp for high school students sponsored by the Ingram School of Engineering . Based on the feedback from post-camp surveys and assessments, both programs were very successful. The faculty team members are regularly involved in many daylong workshops and presentations on green energy and STEM for elementary, middle and high school students and teachers both on campus and at their home schools. Moreover, the College of Science and Engineering (COSE) at Texas State University has long term experience hosting successful and repeat summer camps and programs for junior high and high school students including the nationally reputed *Mathworks Program*, the *Aquatic Adventures Camp*, and *Physics Camp*.

A cross-disciplinary team of experts from Texas State University in engineering, curriculum and instruction, and education with a passion for green technologies and environmentally friendly designs came together and formed a *green energy group* to bring green technology education and practices to the Ingram School of Engineering and to use green technologies in recruitment and retention. The first realized milestone was the establishment of the new System Modeling And Renewable Technology (SMART) lab hosted in the Ingram School of Engineering in 2013. The SMART lab is equipped through a grant from the *State Energy Conservation Office of Texas* and by school matching funds. This lab is equipped with the latest 9KW off-grid solar panel system and 6 wind turbine off-grid systems totaling 5.4KW. The lab has a high-speed power data collection system and analysis server, as well as a real time weather system. The SMART lab is equipped with the tools and equipment necessary to provide hands-on-training and project environments for students and faculty in the area of green energy.

One main mission of the green energy group at Texas State University is to address the STEM education "leaking pipeline" with the goals of increasing students' early interest in STEM careers, enhancing student academic and professional preparation in the green energy industry and increasing retention rates in undergraduate STEM courses. The SMART team set a plan to develop and deploy a series of outreach programs and a university green learning and discovery model to connect with a broader range of students from middle school, high school, community college to undergraduate/graduate students by 1) moving beyond traditional STEM topics through the exciting themes of green energy and environmentally friendly designs, 2) exposing students to careers in the green energy industry, 3) emphasizing the social and moral impact of scientists and engineers involved in the green energy industry and green design technologies and practices, and 4) providing enhanced academic preparation in green energy and making connections to other content learning for STEM students. The green design camp presented in this paper was one outreach activity to realize the mission by early intervention targeting middle school students. The SMART team is continuously working on addressing two main issues:

(i) Shortage in STEM graduates: In the last ten years, a decreasing number of students are choosing to pursue STEM careers. This is particularly true for U.S. students from underrepresented minority groups. [14] Too many students and parents are reported to believe that STEM subjects are too difficult, boring or exclusionary. [15] In addition, although Hispanics and African-American students of college age are increasing as a percentage of the U.S. population, their participation rates in STEM fields are significantly low. [16]

(ii) The need to increase environmental-awareness: The Brundtland Report to the United Nations stated concerns about the deterioration of the human environment and natural resources and their adverse effects on the economy and society.[17]

Green designs encompass environmentally friendly decisions to reduce the carbon footprint, such as using energy sources (i.e. wind energy and solar energy) that can be harnessed with little pollution. Green energy is thought to be an effective way to preserve our environment and natural resources. The proposed interventions through green engineering design practices are expected to have a positive impact on students' interests, performance, and motivation. Most students attending undergraduate programs at this time are part of the Millennial Generation (i.e. students born between 1980-2000). Their shared experiences include great technological advances, globalization, and the Great Recession, and yet, according to an international survey including thousands of Millennials,[18] Millennials may not care about money as much as they care about working with a sense of purpose; they are optimistic, civically engaged, and believe in education and technology as keys to drive change. Therefore, the topics of sustainability and green engineering design are believed to be themes of interest to high school and college students. Such topics will tie STEM fields to broad and meaningful national and global goals, such as preserving our planet, developing environmentally friendly energy resources and reducing pollution, which in turn might appeal to students who would otherwise not have considered STEM careers. [19,20]

The collaborating team of researchers and program instructors believes that the knowledge and values acquired by students through the green engineering design education will have a positive impact on the community, as the students will carry the values and the skills acquired to their careers and communities. "If students are taught how to incorporate green engineering design into their work, then this will help its implementation by industry and lead us to a sustainable future" [21]. Due to such values, the SMART team also believes that green energy education will serve as a point of attraction to improve recruitment and retention in STEM fields to many students, especially women and students from underrepresented groups, as students will pursue learning in a relatable context with a sense of empowerment and fun. [22] Such students may also be more interested in learning that is interdisciplinary. [23] Environmental studies have been found to be connected to "social value and relevance" [24,25] and when properly implemented, has the potential to involve students in work that has a positive impact on society and the environment.[26]

Intervention program

Students applied to the study program, entitled, "Designing Green", by completing a brief application (provided in both English and Spanish) with their name, grade, school, and the following question: "Why do you want to apply to this camp?" The camp itself was selected for funding in a competitive selection process organized by the Texas Higher Education Coordinating Board. The funding allowed the camp costs to be covered, thus allowing selected students to participate free of charge. The camp was offered as a day camp experience (9:00 am – 4:00pm), with no overnight stay.

The program investigators partnered with a local community center in order to reach more families in the community. In addition, recruiting efforts were shared with the local area school district. Recruitment was very successful and all twenty-five of the participant spots were filled within 2 weeks of announcement. Over 100 students were made aware of the opportunity. A diverse group of over thirty students from the local community applied in the first two weeks. A waiting list was kept and 2 spots were filled from the waiting list. A special emphasis was made to recruit self-identified Latino students, and female students. On the first day of the program, student participants as well as their parent or guardian were informed that a research Internal Review Board (IRB) approved research study would be conducted in conjunction with the camp. At that time, parents were able to agree or disagree to participate without any impact upon the continuation of their student in the program. Parents or guardians completed demographic information for themselves and their student.

Program participants

Of the 25 student participants, over 50% were female and 48% were Latino. The demographics of the "recruited" students matched the targeted demographics of the participants (race/ethnicity) as shown in table one below.

Table 1: Student Participants

Student Participants	
Number of Students Enrolled	25
Male	12
Female	13

Table 2: Demographics

Demographics	
White, Non Hispani	*6*
Hispanic	*12*
African-American	*3*
Other	*4*

The camp took place over five days with six contact hours per day (one hour allocated for lunch) or 30 total hours. Students conducted the activities in the camp working in their self-selected teams. These teams were formed on the first day based on random seating proximity with some movement allowances made for friends who expressed an explicit wish to work together. Eight teams were comprised of 3-4 students. The ratio of mentors/leaders to middle school students during the camp activities was 1 to eight. Mentors were diverse faculty and 1 teacher from the College of Education so that the students felt that they had relatable role models.

The theme of "green design", or sustainable design was the umbrella topic for our camp. Within this theme, and over the weeklong program, students were involved in many interactive hands-on engineering and renewable energy activities appropriate to their age and knowledge. Curricula from the Green Education Foundation were leveraged, as well as unique recruitment program featuring green renewable energy for ISOE was developed.

- Team: Seven engineering faculty from different engineering backgrounds designed and delivered the activities. Also, six undergraduate students assisted the teams in their projects.
- Recruitment: Students were mainly recruited from San Marcos Consolidated Independent School District (SMCISD) middle schools in San Marcos, Texas to the weeklong camp. The initial plan was to recruit 24 middle school students of diverse background from the

surrounding community with a special focus on reaching underrepresented student groups in STEM programs (i.e., females and Hispanics). Flyers in English and Spanish were produced and sent to the middle schools and other neighboring schools. 31 Students applied and all were accepted to the program. Six students were unable to participate due to other obligations, so the program served 25 students.

Program curriculum

The following describes program goals and objectives as well as activities and lecture content provided to participants over the duration of the program:

Goal: Attract students, especially underrepresented groups, to the engineering fields and increasing their awareness on the renewable energy

Objective 1: Increase their general knowledge on engineering activities and renewable energy

Objective 2: Increase their interests on pursuing career in engineering

Objective 3: Increase students' understanding of the importance of fundamental mathematics and science preparation in middle school and high school

Activities:

- Interactive lectures using multimedia tools on variety of engineering topics and renewable energy inspired by the LEED standard major topics (Table 2)
- Live advanced machinery tours and hands-on activities
- Discussion and mentoring
- An open ended group project incorporating different engineering skills and renewable energy fundamentals

Table 3: Lecture Topics

Module	Topic	Content
1	**Engineering**	An introduction to the engineering profession. The presentation helps the participant answer common questions such as: What is engineering? What do they do? Who can be an engineer? And how can one become engineer?
2	**Green living**	An introduction to the concepts of green/renewable/sustainable energies and environmental issues. The course will include discussions on engineering ethics.
3	**Green design**	An introduction to the Engineering Design Process, Computer Aided Design, and Green Design Framework
4	**Advanced manufacturing systems**	Fundamentals of automated manufacturing systems including CNC machining, Additive manufacturing (3D printing), and Waterjet cutting.
5	**Engineering in renewable energy**	Fundamentals of different engineering tasks in generating renewable energy including Solar, Wind, and Hydropower. An introduction to distributed generation system integrated into facilities. Students will learn about the solar photovoltaic panel and wind turbines.
6	**Energy conservation by engineering and construction methods**	Fundamentals of topics related to a green building design and green considerations in conscience material selection and landscape design for products and buildings with minimum environmental footprint

In this program each of the topics were covered in the form of lectures followed by hands-on and team working to complete the task toward their green house project. Students participated in a team-based project in which they applied above topics in completing their custom-design green house. Students participated in a project in which teams of three students, as shown below in figure 1, applied a variety of engineering, design, renewable energy, and architectural skills to complete a custom-design green home.

Figure 1. Students working as a team

Students received orientation on high technology tools such as laser cutters and 3D printers. They were also oriented in the use of small handheld tools and had the opportunity to use the hand-held tools and other materials as needed to accomplish their design and building work. In figure 2, shown below, a team of students has used hand tools to finesse their house structure and are independently painting the structure using appropriate safety protocols.

Figure 2. Students demonstrating self-directed use of tools

Students demonstrated their project (Green House), prepared a poster, and answered questions of the panel of experts. In figure 3, shown below, a student is communicates an overview of his team’s employed green engineering design approach and fields questions from an expert review panel.

Figure 3. Project presentations

Study Procedure

Research Questions

The program discussed in the sections above offers a model for an academic sustainability education summer program that is appropriate for engineering colleges interested in reaching middle school students to implement. Further, the research study accompanying this effort aims to address the following research questions:

1. In what ways does a summer intervention program based on the integration of sustainability education and green engineering design impact student career aspirations and awareness?
2. In what ways does a summer intervention program based on the integration of sustainability education and green engineering design impact student awareness and learning of environmental engineering and green design concepts?

Survey

A survey was developed to collect student opinions, self-perceptions and knowledge of various topics as described below. The self-developed combination Likert scale/ open response survey was developed based on some related surveys [27] and unique questions by the authors. Questions covered the topics of student self-perceptions, future careers, and personal characteristics and content awareness. The survey was administered in two parts, each requiring about twenty minutes each to take the survey.

<u>Self Perceptions:</u> 5 Questions- students provide opinions of how they expect to perform in science and math courses, plans for future course taking, and expectations for future career plans.

<u>Envisioning Future:</u> 7 Questions- students provide their interest level to various career fields using a Likert scale.

<u>Attitudes about STEM:</u> 17 Questions – student self-perceptions and attitudes about STEM.

Personal Characteristics and Engineering: 10 Questions – student self-perceptions and attitudes about Engineering & Technology.

Awareness of Sustainability & Green Energy: 12 Questions – student self-perceptions and attitudes about sustainability and Green Energy.

Survey Procedures

All students and their parents were provided an overview of the research protocol. The student surveys were administered on day one to collect pre-program data and these same surveys were administered on the final day of the program to collect post-program data. The results for 18 of the 25 students are currently available and will be reported in the following section.

Data Analysis and Results

Interest in Engineering as a Future Career

Given that this was a camp for which students self-selected as participants, this implied a certain level of interest and motivation in the subject. So, it was expected that they would report being interested in engineering as a future career. In fact, in the pre-survey, 78% reported as being interested or very interested. After the camp, 94% of the students reported as being interested or very interested in a future career in engineering.

Table 4. Pre and Post Student Results: Interest in Engineer as a Future Career

Interest in Engineering as Future Career

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not So Interested	4	22.2	22.2	22.2
	Interested	9	50.0	50.0	72.2
	Very Interested	5	27.8	27.8	100.0
	Total	18	100.0	100.0	

Post-Interest in Engineering as Future Career

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all Interested	1	5.6	5.6	5.6
	Interested	11	61.1	61.1	66.7
	Very Interested	6	33.3	33.3	100.0
	Total	18	100.0	100.0	

58% were interested or very interested in a career doing environmental work. After the camp, 61% of the students were interested or very interested in a future career in involving environmental work.

Table 5. Pre and Post Student Results: Interest in Environmental Work as a Future Career

Interest in Environmental Work as Future Career

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not at all Interested	2	11.1	11.1	11.1
	Not So Interested	5	27.8	27.8	38.9
	Interested	6	33.3	33.3	72.2
	Very Interested	5	27.8	27.8	100.0
	Total	18	100.0	100.0	

Post-Interest in Environmental Work as Future Career

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Not So Interested	7	38.9	38.9	38.9
	Interested	9	50.0	50.0	88.9
	Very Interested	2	11.1	11.1	100.0
	Total	18	100.0	100.0	

Understanding of Green Energy and Engineering Changes

Students displayed a change in their learning of green energy topics and engineering design.

For example, regarding green energy, students (as a group) moved from 40% of students having only a low level awareness to only 17% saying they had a low level of awareness of the topics.

Students displayed a change in their learning of engineering design. Students (as a group) moved from 83% of students having only a low level awareness of the principles and elements of the engineering design process to only 48% saying they had a low level of awareness of the topics.

In the section "Interest in Environmental Work as a Future Career," it was found that the interested plus very interested percentages increased after the camp. However, some students' interest decreased due to their learning and clearer understanding of their interests. This kind of impact is important, because positive or negative, it implies that the camp experience was indeed informative. It should also be noted, that the 'not at all interested' category was not selected by any of the students after their experience, this may indicate that even those students who claimed to not have been interested at all, learned, and were motivated and grew in their interest of STEM due to the camp.

Table 6. Pre and Post Student Results: Understanding of Green Energy

Green Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never Heard of it	1	5.6	5.6	5.6
	A little	3	16.7	16.7	22.2
	Some	3	16.7	16.7	38.9
	A fair amount	9	50.0	50.0	88.9
	A lot	2	11.1	11.1	100.0
	Total	18	100.0	100.0	

Post-Green Energy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never Heard of it	1	5.6	5.6	5.6
	Some	2	11.1	11.1	16.7

	A fair amount	8	44.4	44.4	61.1
	A lot	5	27.8	27.8	88.9
	F	2	11.1	11.1	100.0
	Total	18	100.0	100.0	

Table 7. Pre and Post Student Results: Understanding of Engineering Design

The principles and elements of the engineering design process

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never Heard of it	8	44.4	44.4	44.4
	A little	4	22.2	22.2	66.7
	Some	3	16.7	16.7	83.3
	A fair amount	1	5.6	5.6	88.9
	A lot	2	11.1	11.1	100.0
	Total	18	100.0	100.0	

Post-The principles and elements of the engineering design process

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never Heard of it	1	5.6	5.6	5.6
	A little	2	11.1	11.1	16.7
	Some	5	27.8	27.8	44.4
	A fair amount	5	27.8	27.8	72.2
	A lot	4	22.2	22.2	94.4
	F	1	5.6	5.6	100.0
	Total	18	100.0	100.0	

Discussion & Conclusion

Often, university outreach programs for middle school students are not purposefully designed so they do not integrate the objective topics well. Many organizers are guided by the presumption that hands-on activities are motivating, but this is not enough if the topics are not aligned well to the learning needs of the students. In the week -long program presented in this study, students were involved in hands-on sustainability education (green engineering and green energy) activities appropriate to their age and knowledge while including exciting topics: the engineering design process, CAD solid modeling, 3D Printing and water jet cutting. Using project-based learning, student teams participated as designers of their own green home models by integrating their learning. Pre and post surveys revealed increases in student awareness of general engineering and renewable energy concepts as well as increased interest in pursuing engineering careers. Some elements to consider changing in the future would be to focus more on direct examples of technologies useful in the green design field. However, this is a model that we will continue to implement and would recommend to others.

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