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IMPLEMENTING ENGINEERING AND SUSTAINABILITY CURRICULUM IN K-12 EDUCATION

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ABSTRACT

Introducing students to engineering concepts in early education is critical, as literature has shown that students' degree of comfort and acceptance of science and technology is developed very early on in their education. While introducing engineering as a potential profession in K-12 classrooms has its own merits, it has also proven itself to be useful as a teaching tool. Engineering can lend itself to concepts that can engage students in critical thinking, problem solving, as well as the development of math and science skills. In engineering higher education there has been an increased focus on industrial ecology and sustainability in order to help students understand the environmental and social context within today's society. The authors of this paper discuss the importance of these attributes when introducing engineering to K-12 students. Engineering and sustainability are not two mutually exclusive concepts, but sustainability should be considered throughout the practice of the engineering discipline. The ADEPT (Applied Design Engineering Project Teams) program at the University of California, Berkeley was established to design and deploy a standards-based engineering curriculum for middle schools and high schools (grades 6-12) designed to integrate mathematics and science concepts in applied engineering projects, inspire secondary students, and strengthen the classroom experience of current and future faculty in math, science, and engineering. This paper discusses the importance of introducing engineering and sustainability in K-12 classrooms. Example modules that were developed through the ADEPT program are presented as well as a set of recommendations that were designed as a guideline for educators to incorporate engineering and sustainability in K-12 classrooms. While the module discussed here was designed for middle school students, the curriculum and criteria recommended can be adapted to primary and secondary education programs.

INTRODUCTION

While many high school programs continue to introduce students to science, engineering, and technology, studies have shown that students' degree of comfort and openness to these subjects are developed very early on in their education [1, 2]. Despite these efforts, many students are unaware of what engineers do and therefore do not consider engineering as a career possibility, compared to other professions such as law or medicine. While introducing engineering as a profession in K-12 classrooms has its own merits, it has also proven itself to be useful as a teaching tool. Engineering lends itself to concepts that can engage students in critical thinking, problem solving, as well as the development of math and science skills. However; it can be difficult for teachers to develop engineering curriculum for the classroom due to time constraints, limited access to resources, and lack of knowledge about the benefits and potential success of this topic in the classroom. In addition, teachers and students may hold misconceptions about engineering-- that it is too challenging or beyond the ability of students in lower grade levels.

To address these issues, the ADEPT (Applied Design Engineering Project Teams) program at the University of California, Berkeley was established to design and deploy a standards−based engineering curriculum for middle schools and high schools (grades 6−12) designed to integrate mathematics and science concepts applied in engineering projects, inspire secondary students, and strengthen the classroom experience of current and future faculty in math, science, and engineering. This program was funded by a National Science Foundation Graduate STEM fellows in K−12 education grant. ADEPT curriculum development teams combined the best of inquiry and activity-based teaching and learning with cutting edge university research and resources. Each team was made up of local school teachers (Teacher Fellows), graduate students (Graduate Engineering Fellows), university faculty, and advanced undergraduates. Each team member contributed unique perspectives and skills in the creation of discrete curriculum modules. These modules act as exemplary "hands-on – minds-on" engineering projects as model lessons that enrich the learning experience of the entire range of secondary students.

The overall goals of the program were to: engage middle and high school students in doing mathematics and science through engineering projects that strengthen their understanding of core concepts in math and science; inspire and enrich learning for the diverse population of middle and high school students found in urban classrooms; create and sustain a vibrant learning community of teachers, graduate students, undergraduate students and university faculty who work together to develop exemplary curriculum modules; foster a college-going culture among middle school students, parents, and teachers that provides a supportive and attractive alternative to counter--academic pressures confronting students when they make the transition from middle school to high school.

ADEPT teams designed and developed modules to serve the needs of the full range of students in grades 6 to 12, including those who do not learn core math and science concepts with current curriculum and teaching methods. These "hands-on – minds-on" engineering design projects tap into a greater range of learning modalities than current textbook and classroom practices. Second, ADEPT modules serve the needs of students who have mastered the core math and science concepts and are challenged by the open-ended opportunities to integrate these math and science concepts, and apply their understanding in engineering projects that have implications for their lives and their community. Each ADEPT Project Team consisted of one Math and one Science Teacher Fellow, two Graduate Engineering Fellows, a university faculty, and undergraduate tutors. Together they helped secondary students succeed in math and science through comprehensive in-class academic support and engineering project modules.

SUSTAINABILITY AND ENGINEERING

The rapidly growing complexity of the world expresses itself in a need for students who are technically competent and able to understand the environmental and social context within which today's engineering occurs [3-5]. This has led to an increasing focus on industrial ecology, and demands to develop "sustainable engineering" theory, practice, and educational modules [5]. Sustainability is often defined as the ability to meet the needs of today without compromising the needs of tomorrow. It is also important to address the three pillars of sustainability, which are economic, environmental, and society, when developing curriculum that integrates sustainability. Most literature focuses on sustainability in the classroom at the collegiate level; however some U.S. states are adopting K−12 integrated environmental and sustainability learning standards to be integrated into core content areas across all grade levels [6]. The authors of this paper recognize the importance of these attributes when introducing engineering to K−12 students. Engineering and sustainability are not two mutually exclusive concepts and sustainability should be integrated throughout the practice of the engineering discipline. In addition, today's students are much more aware of the environment and the impact they have on it than the previous generation. This is an opportunity to teach students that their actions have an effect and that through their actions; they can make substantial differences in this world.

INTRODUCTION TO ENGINEERING 101

At the beginning of the school year, before discussing engineering with each class, a pre-assessment survey was administered to the class. The survey was used to determine the pre-existing level of knowledge that a student had about engineering before going through the Introduction to Engineering 101 module. One of the goals of the ADEPT program is to introduce students to engineering as a possible career path and to inspire future engineers. Using a pre and post assessment survey, we can begin to understand whether students have an increased understanding of what engineering is and the potential applications of engineering as a future career.

After giving students the survey, ADEPT graduate fellows gave a presentation to the class about themselves and engineering. To allow the students to be able to relate to the graduate students, presentations covered topics such as where the graduate student grew up, information about their family, as well as hobbies and interests. The presentations also included information about the graduate student's research and included an overview of engineering and the different disciplines of engineering, including examples of industries where engineering was applicable. Next, the graduate students took the students through the introduction to engineering 101 modules and introduced them to the engineering design process based on the previous work of Mangold and Robinson [7].

ENGINEERING DESIGN PROCESS

The authors have previously noted the importance and benefits of using the engineering design process (EDP) to bring engineering into K-12 classrooms [7]. The EDP is a decision-making process, typically iterative, in which the basic science, math, and engineering concepts are applied to develop optimal solutions to meet an established objective. Figure 1 shows the diagram of the EDP. Among the fundamental elements of the design process are the development of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. Several experts in the field of technological education have provided strong evidence that engineering design should be the central focus of technological education [8-10].The design process, the engineering approach to identifying and solving problems, is (1) highly iterative, (2) open-ended, in that a problem may have many possible solutions, (3) a meaningful context for learning scientific, mathematical, and technological concepts, and (4) a stimulus to systems thinking, modeling, and analysis [11].

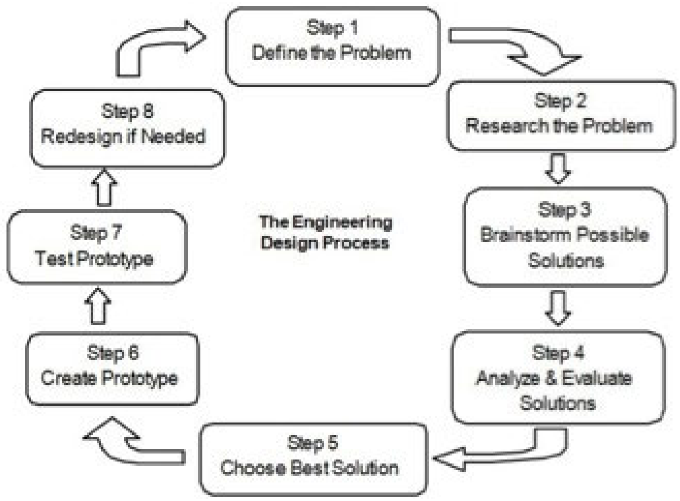

Fig. 1: Engineering Design Process Diagram

In all of these ways, engineering design is a potentially useful pedagogical strategy. Analysis is one of the key ideas that are new to K-12 education. Once students select a potential solution, they analyze and evaluate the solution to determine if it is the optimal solution. This step in the process extends beyond just trying to get the "right" answer, but helps students realize that there can be more than one right answer. This type of learning is not typically introduced in early childhood education. The importance of analysis has been addressed previously in literature. One of the true values of engineering study is the development of real-world critical thinking and meta-cognition skills; skills that are adaptive in nature and applicable to areas beyond engineering. However, the development of these skills is commonly left to the humanities. The EDP lends itself to this type of study due to the iterative nature and analysis of varied potential solutions. Also, it is important to point out that the EDP, while coined as a design process, can be used beyond design.

MODULE IMPLEMENTATION

The engineering modules focused on introducing students to various topics in engineering as well as the graduate students' research topics, expanding on students' math and science skills, and focusing on hands-on projects to engage students. Throughout the school year, the graduate students each worked 20 hours a week in the classroom for the entire school year with the science and math teachers and students. The main focus of the ADEPT program was the development and implementation of engineering modules into the existing classroom curriculum. Graduate students were responsible to develop two engineering modules to implement into the teachers' curriculum; one engineering module that explained their current research and one engineering module that took a section of the teachers existing curriculum and developed it into engineering hands on module. All modules were required to be aligned with state standards and current curriculum topics. Through these modules, students were able to learn about engineering, improve their math and science skills, and engage in hands-on, minds-on projects.

The interests of the instructors were in developing a curriculum that:

- focused on learner-centered, open-ended, and constructivist activities,
- introduced pre-engineering skills that are not typically addressed in K-12 education,
- exposed students to an authentic engineering working environment, included team oriented projects, and
- guided students towards adaptive critical thinking, to engage them in developing meta-cognitive skills.

SUSTAINABILITY FOCUSED MODULE

Sustainability can be introduced into the classroom in many ways. It can be introduced as a stand-alone topic or integrated into existing curriculum.

One example of how to introduce sustainability as a stand-alone topic comes from one of the resulting modules from the ADEPT program, which focused on introducing students to sustainability and the concept of their carbon footprint -- how to calculate their current footprint and methods and behaviors that can reduce their carbon impact. Before beginning the module, a pre-module assessment was administered to measure the students' prior knowledge and understanding of sustainability. Next, the graduate student gave a presentation on sustainability and how it relates to engineering, and the importance of sustainability in our society. Next, the class worked through a worksheet together to introduce some key topics needed to begin the sustainability module. Then for fun the class did some word search puzzles containing sustainability concepts to help familiarize the class with key vocabulary they would encounter in the module.

Before beginning the project, a letter to the parents/guardians was sent home with each student. The letter explained that the students were going to be working on a sustainability project and that they would be asked to collect data from home over the next three weeks. It is very important to get support from the parents, to not only assist the students with the data collection, but to engage the entire family in a conversation about sustainability and ways to reduce their carbon footprint.

The letter also included a grading rubric for how students would be graded on their data collection piece of the project:

To Get an 'A'	To Get a 'B'	To get a 'C'
Three weeks of Data	Two Weeks of Data	One Week of Data
High Level of Accuracy All data cells are complete.	Medium Level of Accuracy Most data cells are complete.	Low Level of Accuracy Some data cells are complete.

Lastly, students were to get the bottom of the letter signed and return it to class, to confirm that they would have support at home in collecting the data needed to complete the project. While learning about fossil fuels, alternative fuels, and renewable energy, students were asked to collect data from their homes over the course of three weeks. This data included transportation (mileage, mode of transportation (e.g. public transit), food consumption (dining out and groceries), and electricity and gas use for one month. Students were given data sheets (one for each week) to bring home to fill in the data needed to complete the assignment. After students collected three weeks of data, the students combined their data and entered in the total amount to the totals sheet that they were given.

Using the data listed on their totals sheet, they input this data into a free online, carbon footprint calculator program developed by researchers at the University of California, Berkeley: http://coolclimate.berkeley.edu/carboncalculator in order to analyze their data. This program calculates the carbon footprint of the student's household. A sample result screen can be seen in figure 2. Every student in each of the 6 classes recorded their results and then the class worked together to add up each student's carbon footprint to get a total carbon footprint for the entire class.. Then the classes entered into a competition with each other to see which class could lower their carbon footprint the most.

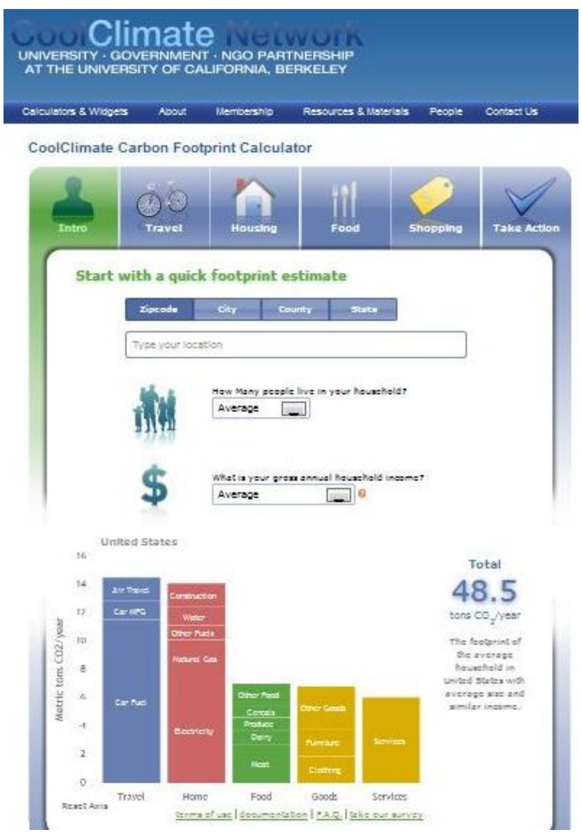

Fig. 2: Online Carbon Footprint Calculator

To facilitate this, a second class discussion was held in order to discuss ways to reduce their carbon footprint and brainstormed different activities they could adopt in their homes and daily lives, e.g. riding their bike to school, carpooling, turning off the lights when not in use, limiting their TV viewing time, using a blanket instead of turning on the heat, etc.

Next, the students repeated the data collection process mentioned above and collected another round of data for an additional three weeks. After all data has been collected and totaled, the classes compared their before and after carbon footprints in order to determine which class was able to reduce their carbon footprint. Figure 3 shows a sample of the data collected by the classes.

At this time, teachers have the option of introducing students to topics such as statistics, data error, and other concepts based on the grade level of the students. In addition, the science and math teachers can work together and have the students graph their data in different forms to develop their graphing skills. Computer class teachers can also use this module to introduce graphing and data analysis tools using a program like Microsoft Excel to learn data visualization techniques.

	Housing	Transportation	Food	Total
AM R2	9.1	11.9	65.0	86.0
PM R2	9.4	11.6	72.6	93.7

Round 2

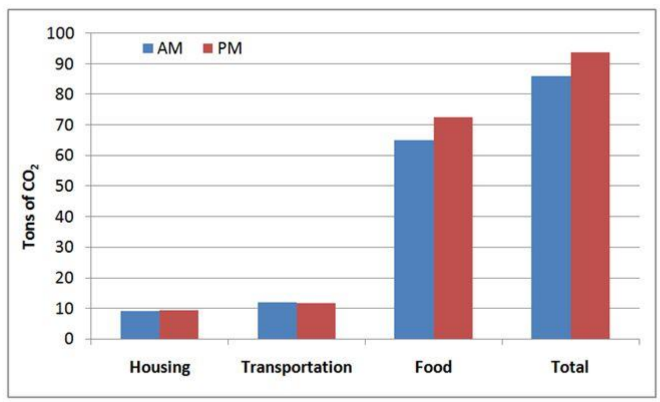

Fig. 3: Carbon Footprint Data for AM and PM Classes

Lastly, the module can be wrapped up by a discussion of the results. Students can discuss what methods they employed to reduce their carbon footprint. Students can also discuss what activities or changes they think had a bigger impact on reducing their carbon footprint based on the data and using the online carbon footprint calculator. Students can discuss whether it was easy or hard to make the changes and whether it was easy or hard to influence others in their household to employ methods to reduce their carbon footprint. Teachers can also take this opportunity to discuss the "uncertainty" or "error" in the results.

It was the teachers' hope that students would learn that even they, by their choices of what snacks to buy or how they get to certain places (walk, ride a bike, or be driven) they can make a difference in their own carbon footprint. This exercise may in turn inspire students to inform people in their own lives as to how they can help reduce their personal carbon footprint.

Surveys, interviews, and pre and post assessments were used to measure the effectiveness of the curriculum in the classroom, both at the teacher and student level. While the module discussed here was designed for middle school students, the curriculum and criteria recommended can be adapted to primary and secondary education programs.

SUSTAINABILITY INTEGRATED MODULES

As mentioned previously, sustainability does not have to be introduced as the main concept of the curriculum but could be integrated through modules and lesson plans that are already used by the teacher. The following five modules are examples of curricula that were developed by the ADEPT fellows that do not have sustainability as the main focus. However; sustainable concepts and ideas can be introduced and integrated into these modules. For example, material selection, renewable energy, climate change, and conservation are all concepts that could be incorporated into existing curricula. Typically the sustainability curriculum focuses on the environmental impacts of a system or design. The authors encourage this topic to be explored at an individual level and to be expanded to also include the economic and social implications of sustainability. Examples of economic sustainability concepts could include the financial impact of a design decision or trade-offs that could be made. To address social sustainability, various concepts that address the impacts on workers and the surrounding community could be addressed. Below are brief descriptions of some modules developed by the ADEPT program. At the end of each module are some suggestions for example sustainability concepts that could be integrated into the module.

1. Fun with Polymers module
Purpose: Introduce students to polymers and the concepts of elasticity, plasticity, and cross-linking. To have students make different polymers and compare their physical properties.
Topic: Chemical Engineering, Polymers, Polymer Chemistry
Grade Level: 8th Grade Physical Science
Lessons learned by the graduate student: Students were very enthusiastic about hands-on activities. Students found it difficult to use the vocabulary they acquired from the module. Designing test questions that assess how much students have learned is a difficult task.
Sustainability Concepts: Green chemistry, Material selection, Human health & safety

2. Boat module
Purpose: Reinforce concepts of mass, volume, density, and buoyancy. Introduce the engineering design process.
Grade Level: 8th Grade Physical Science
Activity: Design and construct a boat out of clay that meets the following criteria:

- floats
- holds 20 pennies of 'cargo'
- sails across a 'pond'

Data collection:

- initial & final mass of clay/boat
- initial & final volume of clay/boat
- sketches of each prototype
- modifications made for each prototype

Sustainability Concepts: Environmental impacts associated with transportation, Fuel emissions, Global warming potential

3. Mold module
Purpose: Investigate molds and their growth. Design experiments to test growth variables. Gain a sense of the size of microscopic features.
Grade Level: 7th Grade Life Science
Activity: Sample mold spores in the school

- Test mold growth with various conditions: moisture, nutrients, spores
- Examine the microstructure of mold using the microscope

Reflection:

- Bridge to the real world - mold grown on food, walls and ceilings, etc…
- Encourage students to make hypotheses addressing their own questions
- Help students generate ways to test their hypotheses

Sustainability Concepts: Human health risks, Green chemistry

4. Structures module
Purpose: Build bridges in order to gain a practical understanding of structures including materials, shapes, forces, and loads. Students are responsible for bridge construction, design, earthquake simulation testing, and redesign in the event of bridge failure. Students will learn to work in teams with real-world situations and budget constraints.
Grade level: 6th Grade Math and Earth Sciences
Concepts:

- Structures - materials, shapes, forces, loads, and material strength
- Observe the relative movement of building blocks under different loading conditions
- Recognize how different materials contribute to the structure stability

Sustainability Concepts: Structural safety, Economic considerations, Material selection

5. Engineering Design Process
Purpose: Expose students to an approach to engineering design.
Grade level: 8th Grade Mathematics and Physical Science
Lesson: Apply engineering design process to a water bottle rocket project to further:

- Understand the stages of the design process
- Tie together phases of the design process
- Investigate the interaction between a hands-on project and scientific learning
- Emphasize the iterative nature of design

Sustainability Concepts: Economic considerations, Material selection, Environmental impacts, Fuel emissions

More detailed information and additional sample modules from the program can be viewed at: http://coe.berkeley.edu/cues/pep/adept/index.html

KEY TAKEAWAYS AND RECOMMENDATIONS FOR K-12 EDUCATORS

As a result of this work, the following are some key takeaways:

- It is important to introduce students to engineering early in their education
- It is important to introduce sustainability to students
- Engineering and sustainability should coexist
- It is important to integrate engineering concepts with math and science skills
- Developing modules that adapt easily to the teacher's current curriculum ensures the long term success and continuation of the modules created
- It is important to engage the teacher and co-create the modules whenever possible
- It is very valuable for graduate students to have the opportunity to work with and explain their research to K-12 students – can inspire and serve as role models
- It is very important to introduce the engineering design process [7]

From this work there are some recommendations for K-12 educators when using introducing engineering into the classroom:

- It is beneficial to integrate engineering modules into existing curriculum in order to reinforce classroom concepts
- When introducing engineering to K-12 students, connecting the concepts and lessons with real world examples encourages constructivist and experience based learning
- Engineering easily aligns with state standards and can help students understand applications of math and science concepts
- The engineering process is easily adaptable to current curriculum and encourages students to step through the problem solving process

When introducing students to sustainability, three main objectives are to:

- Understand basic concept of sustainability
- Understand human connection to the natural world
- Have the knowledge necessary for improving sustainability

SUMMARY & CONCLUSIONS

The authors have experienced the success of introducing engineering and sustainability in K-12 classrooms first hand. As students and teachers are engaged early in student's education around these concepts, both motivation and comfort for these topics develop. Through hands-on projects that invite exploration in a team environment, students demonstrated developing knowledge into key concepts of engineering and sustainability. The ADEPT program introduced the development of sustainability through their modules. A design based on green or sustainable design extends beyond baseline engineering quality and safety specifications to consider environmental, economic, and social factors [12]. The authors of this paper believe there should be no exception to this when introducing the engineering design process to K-12 students. Sustainability should be part of the initial conversation to consider the lifecycle impact of products or processes that are being developed.

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