Engineering Education Project to Promote Active Learning through Innovative Teaching on Power and Energy

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***Abstract*—While virtual learning environments have dominated for the past few years due to the pandemic, the effectiveness of hands-on activities has been gaining attention again. The participation of college students in community outreach programs was once widespread, but their role as active contributors to primary education has not been studied in depth. This study aims to create a space for a convergent STEM educational program that can benefit both the participating college students and the elementary school kids who can learn from those students. As a pilot project, the authors aim to present how they set up the program from the engineering students' perspective first in this paper. The educational materials used for this study and the project procedure are described in detail, along with some positive results from the participating engineering students in the program.**

Keywords—STEM, engineering education, community outreach, power and energy, innovative teaching

I. INTRODUCTION

In the new global economy, society needs a workforce with the knowledge and skills to compete. A new workforce of problem solvers, innovators, and inventors who are self-reliant and able to think logically is one of the critical foundations that drives innovative capacity in society. A key to developing these skills is strengthening science, technology, engineering, and math competencies in every K–12 student.

The development of science, technology, engineering, and mathematics (STEM) traces back to the Morrill Act of 1862, which created land grant universities to promote agricultural science. The Act later established engineering programs as well. When more land grant institutions emerged, STEM training expanded beyond education and began penetrating the workforce. In the twenty-first century, a consensus emerged that U.S. students' achievements in the STEM disciplines were falling short compared to other industrialized countries. The year 2001 saw a push to address the shortfall. The National Science Foundation (NSF) created the acronym STEM to reflect the standards in science, math, engineering, and technology that educators would follow to teach K–12 students problem-solving, analytical thinking, and science competencies. That same year, the NSF Director of Education and Human Resources changed the acronym to STEM [1].

Technology is changing faster than ever, and utilization and dissemination of technological development are becoming more important. For the field of engineering to not only be in a high-dimensional scope but also be relevant in our daily lives, it is essential to teach the fundamental principles of engineering, where the elemental organization and utilization of engineering are understood. Especially in this post-pandemic and AI era, when we are relying on science and technology from the visible to the invisible, it is urgent to provide education that not only benefits from but also actually touches and gets close to science and technology. This study is designed to organize interdisciplinary research to expand the role of engineering students who interact with science and technology in their lives, are trained about current research and technology, and are sensitive to changes in the near future while suggesting problems in current public education and drawing a blueprint for research that fills the holes.

The practice of sharing knowledge promotes and enhances the economic state of society, and a solid and active engineering education is essential for the growth of society. Our educational system must prepare the engineers and scientists of the future to tackle new tasks and embrace new possibilities. Thus, engineering education aims to teach engineering concepts and practices to the next generation of engineers, who will utilize their knowledge and expertise to design, construct, and maintain the systems and technologies that society requires [2]. However, we can expand the target range of students for engineering education from typical college students to those in primary education. For society to survive and prosper, younger students in STEM areas are critical, as these youngsters will grow up to be the ones creating, advancing, and constructing our rapidly transforming world. Attracting those younger generations into the relevant fields should be a prerequisite for sustainable growth in engineering and technological development. Therefore, engineering education, particularly through community outreach programs, may inspire more comprehensive and practical STEM education [3], [4]. Some studies argue that engineering education through community outreach allows engineers and other participants to engage in active learning by participating in hands-on activities and problem-solving, then subsequently integrating this learning through further discussions and evaluation [3], [5]–[8].

This study aims to develop a space for convergent STEM education in primary education and to report the preliminary stages of a study to develop and evaluate a project that provides hands-on STEM education for students to develop a strong foundation in engineering through more direct and efficient access to the sources and principles of technology in the age of technological information. The outcome of a successful STEM education is not only that children learn the concepts required for STEM but also that they become STEM creators and developers themselves, using STEM tools to master the skills and principles embedded in STEM creations, and can work alone or in teams to replicate and reproduce those skills in other contexts as needed. This research is a project to train engineering students who are currently learning and training with the most advanced science and technology as STEM education creators to develop lectures and activities using STEM tools on topics important for engineering convergence education and to expand engineering students as contributors to STEM activities through community outreach by taking the Far West to public education sites and providing educational materials directly. Currently, the project is planning a follow-up study to introduce the development process to engineering students at a highly-ranked university and to receive more feedback on its impact and effectiveness in the educational field.

II. Justification of Study

A. Why is Community Outreach by Engineering Students or Engineering Research Teams Necessary?

Undergraduate engineering students can describe their recent experiences of applying to and attending college. The research teams of engineering departments can provide the most updated information, address the current developments in the fields, and know how to provide in-depth information on questions from teachers and students in K–12 education. As mentioned, engineering technology development has taken place rapidly, and it is vital to question if K–12 education has updated fast enough for young students to follow the current society and technological enhancement. The Ministry of Education should provide meaningful opportunities for students to connect to their society, and realistic information can transform students through teaching and activities run by professional groups in the fields.

B. What Role Do Engineering Students Play, and What Impact Can They Make in Community Outreach?

We argue that a hands-on STEM curriculum can help students learn in a way that connects their thinking and development across different fields. For example, activities that embody knowledge through hands-on activities provide an opportunity to demonstrate a practical application of knowledge through STEM. Project-based education is essential for young children who need to combine the scattered knowledge learned in school to become a crucial educational asset in a future society that has to rely on advanced engineering skills and technology enhancement. Beyond acquiring pure STEM skills through hands-on activities, creative skills (creativity) can be developed by learning mental skills and expanding critical thinking to express ideas from the simplest to the most abstract.

We are a participatory research project that prepares university students to become contributors to transforming their learning with updated information from science, technology, engineering, and mathematics (STEM) teachers. Power and Energy Group Outreach Project at Texas A&M University strives to inspire college students to take an active interest in the innovative STEM curriculum that will provide transformative learning of STEM knowledge to K–12 students responding to a new paradigm of understanding energy and newer technology enhancements on rapid change in demand for energy. The ultimate goal of the project also reinforces the idea that the college students in the research project can learn to collaborate with education and develop communication skills in sharing current issues with future citizens through systematic practices and an opportunity to teach in K–12 public schools. Through these collaborative practices, we are changing the world, one successful future scientist, engineer, and mathematician at a time.

III. Materials and Procedure

A. STEM Hands-on Tools

Students can utilize tools to practice essential activities linked to the abilities they need to develop, review some ideas in greater detail, and delve deeper. The STEM tools we use are to build demonstration items when they visit classes in elementary schools, which is an apparent objective, but also for the engineering students to have an opportunity to create what they are interested in rather than being instructed by instructors. We mainly use two educational tools: 4Dframe and Arduino.

1) 4Dframe kits: One of the significant and unique experiences provided to participating college engineering students is manipulating the newly developed STEM tool called 4Dframe. 4Dframe is an educational tool developed explicitly with STEM education in mind. It consists of two main components: tubes and connectors. Tubes are available in different lengths and colors, and connectors are also available with varying numbers of legs and shapes to connect tubes in almost any direction and angle. Key aspects of the 4Dframe frame are flexibility and portability. The tubes and connectors can be easily bent by hand or cut with a knife or scissors. Such characteristics allow users to make almost anything they can imagine with a wide variety of components. Also, they are pretty small and lightweight as they are made of thin plastic, so little space is needed when manipulating or carrying them. 4Dframe was chosen because it has great potential for engineering students to enhance their learning experience, as they can build and test what they have learned in class with their own hands without many limitations.

2) Arduino kits: Arduino is a circuit board with a microcontroller that is programmable with its software. Arduino kits have been popular for STEM projects due to their low cost and accessibility. Even those with limited knowledge of electronics can quickly learn how to operate them for the majority of STEM applications. Engineering students who have not had much experience with microcontrollers are able to learn how to use them fairly quickly with little time and effort.

B. Project Procedure

1) Participants: Recruiting was done in a power systems course in the Department of Electrical and Computer Engineering at the beginning of the semester. A total of 36 students volunteered to participate in the project and were grouped into ten teams of 3 or 4 students each. Some of them applied as a group, while those who applied individually grouped themselves after the kick-off meeting.

2) Meetings: Virtual or in-person meetings were held on Fridays. 30-minute virtual meetings were held for each team with the researchers of this study for collaboration within each team, and teams reported what they had done based on the feedback from the previous meeting. The in-person meetings were held with all the participants for whole-group collaboration for one and a half hours, as shown in Fig. 1. Each team discussed their progress, challenges, and possible solutions. After that, other teams provided feedback and comments. The first in-person meeting was to introduce team members, choose a team name, and decide what topic and product each team wanted to work on. The themes given to all the teams were Power and Energy so they could have unity in choosing their lesson topics. The second in-person meeting was held to share their initial ideas about their topic and what product they would create.

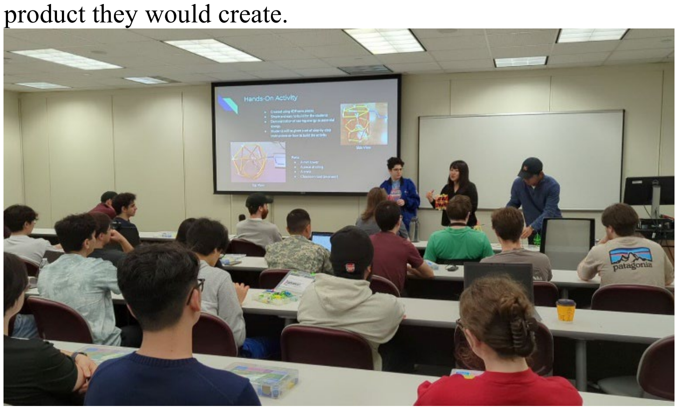
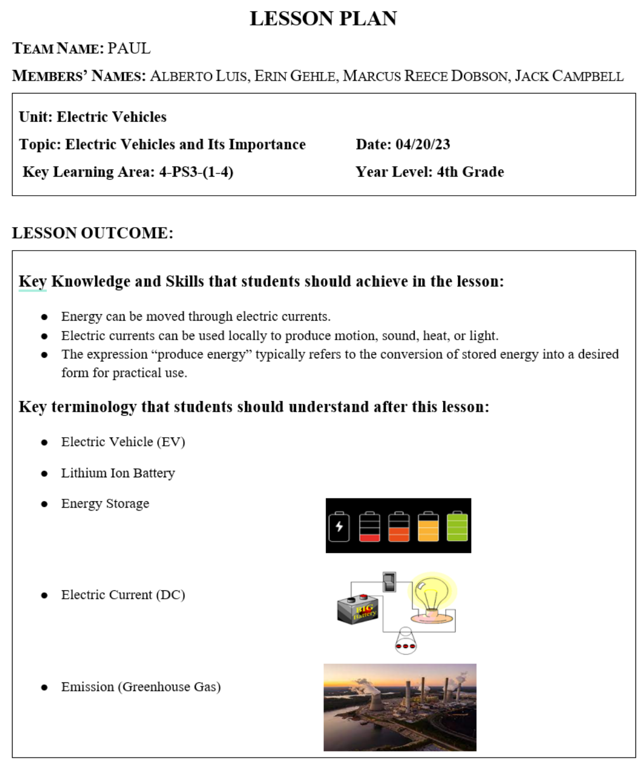


Fig. 1. In-person meeting with all the participating engineering students

3) Literature review: Once all the teams had chosen the lesson topic, they were tasked with doing literature reviews. This allowed them to do in-depth research on the subject of their choice, such as finding important definitions or terms to clarify their topic's historical, political, societal, or environmental backgrounds. They were also required to summarize the primary background knowledge they should know to ask or answer questions about for their lesson plan. Their literature review was presented in one of the meetings, and each team got feedback and comments from other teams and the project researchers. Some of the questions that can or should be answered in their literature review presentation are as follows:

- What are the major historical issues in the past, present, and future?
- What are the main questions to update to understand the topic critically, and how would you answer them?
- What are the political, societal, or environmental standpoints? What are the major current issues?
- How would you clarify the definitions or terms of your topic, and how would you set up some examples that children can be connected to (reflection)?
- Provide references to the resources.

4) Lesson plan: As this project was conducted with visiting a local elementary school in mind, students were tasked with writing a detailed lesson plan, as shown in Fig. 2. For that, we invited the principal of a local elementary school for a seminar, and students were able to ask questions regarding the uncertainties they had in writing their lesson plans. Also, researchers provided the students with Texas Curriculum Standards and Next Generation Science Standards to understand what to expect from the kids they are targeting for their lesson. Thus, students knew the understanding level of the topics the kids would have and could develop their lesson plans accordingly.



LESSON PLAN

TEAM NAME: PAUL

MEMBERS' NAMES: ALBERTO LUIS, ERIN GEHLE, MARCUS REECE DOBSON, JACK CAMPBELL

Unit: Electric Vehicles
Topic: Electric Vehicles and Its Importance **Date: 04/20/23**
Key Learning Area: 4-PS3-(1-4) **Year Level: 4th Grade**

LESSON OUTCOME:

Key Knowledge and Skills that students should achieve in the lesson:

- Energy can be moved through electric currents.
- Electric currents can be used locally to produce motion, sound, heat, or light.
- The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use.

Key terminology that students should understand after this lesson:

- Electric Vehicle (EV)
- Lithium Ion Battery
- Energy Storage
- Electric Current (DC)
- Emission (Greenhouse Gas)

Fig. 2. One of the lesson plans about electric vehicles

5) Reflection: Three reflections were gathered from the students during the project through a Google Form for the researchers to see how the students were doing and what challenges they had to help them progress in the project. This was also a way to collect any artifacts the students had created to document their progress. Some of the questions asked in the reflections are as follows:

- What was your significant role in setting up your project, and why do you think it was vital for yourself and your team?

- Please provide some original ideas from you and your team. What ideas of yours have been confirmed after brainstorming and planning?
- Provide any artifacts (particularly any sketches, drawings, or pictures involved) to support your answers above.
- Please write anything you want to share, including any extra information or questions about your progress.

6) Final deliverables: Students had to make four final deliverables: lesson plan document, recorded presentation, circuit instruction, and 4Dframe main product with mini activity instruction. The lesson plan document included the topic, key learning area in the standard provided, target education level, lesson outcome, lesson structure, recommended teaching approach, and assessment questions regarding the lesson. The recorded presentation was made as a voiceover accompanying their PowerPoint slides about their overall experience with the project. The circuit instruction explains where to check and how to fix the circuit if it does not work. The 4Dframe main product is the item students had made over the two months using 4Dframe kits and Arduino kits to demonstrate their lesson topic if they go to a local elementary school. The mini-activity instruction described how to lead kids through the mini-activity created with 4Dframe after their lesson.

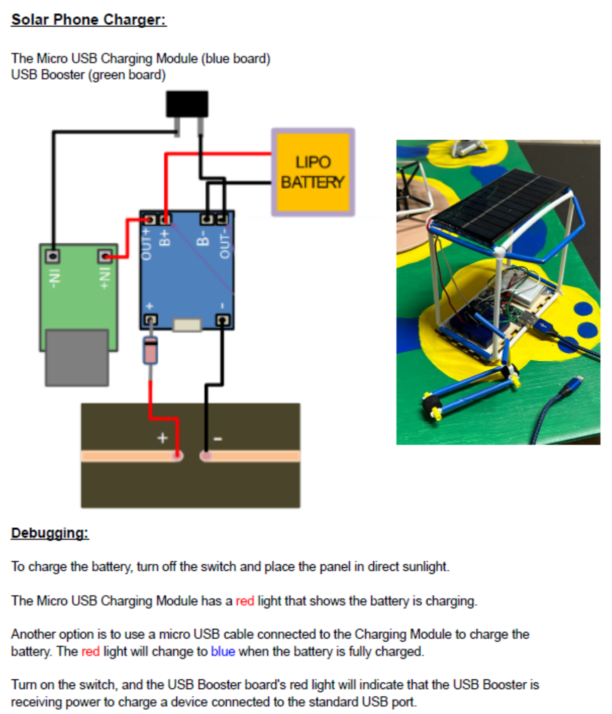


Fig. 3. Circuit instruction explaining how to debug a solar charging station

IV. Results

A total of 36 engineering undergraduate students, divided among 10 teams, participated in the project. All the teams successfully finished the project with satisfying performance. Some teams visited a local elementary school and taught a class of 4th-graders. They demonstrated the 4Dframe product they had made at the beginning of class and gave lesson presentations based on the lesson plan in the middle. Lastly, they led a mini hands-on activity for the kids to make something related to the topic with 4Dframe. The schoolteachers were happy that their kids paid attention to STEM topics for the entire class time and learned something new. They also said seeing the kids listening to college students carefully and asking endless questions about their lesson topics was very rewarding. Most of the engineering students said they learned quite a bit about the subject they chose through the literature reviews, making the 4Dframe product of the topic, and trying to explain it with easier words for kids.

Fig. 4. Elementary school kids in a mini-activity after the lesson led by engineering students

The summary of the two teams' work is introduced below.

A. Vinette #1: Wind energy realized with 4Dframe

Engineers created wind turbines to use the wind as a reliable, clean, and sustainable energy source. In many parts of the country, wind energy offers a practical and affordable substitute for conventional power generation. The rotor blades spin the hub (center) of the turbine to convert wind energy into electricity. An electric generator, a revolving machine housed inside the turbine, produces electrical output with voltage and current. Electricity is generated based on electromagnetic interaction between the spinning rotor working as a magnet (either electro or permanent) and the coils of wire in the outer structure.

By creating their own small wind turbines and seeing the electric power they generate, engineering students understood how engineers convert wind energy into electrical energy. They also investigated how the layout and positioning of the blades impact the amount of power generation with two different blade orientations. The vertical wind turbines have their blades rotating on a vertical axis, while the horizontal wind turbines have their blades rotating on a horizontal axis. The differences between the two types of wind turbines were also emphasized through the literature reviews by the students. Vertical turbines are the most common ones we can see driving on highways, typically generating more power output. On the other hand, horizontal turbines are more suitable for smaller land and places where wind directions are more variable since they do not have to point toward the wind as they do for vertical ones. Also, students found that horizontal turbines may be more useful in the future, where more renewable energy sources are required, with the possibility of installing them in cities or on tall buildings.

The team built miniature wind turbines that harness wind power to produce electricity. 4Dframe was used to build the structure and different types of turbine blades, and a DC motor was used as a generator. Fig. 5 shows the sketch of the initial designs and the first models.

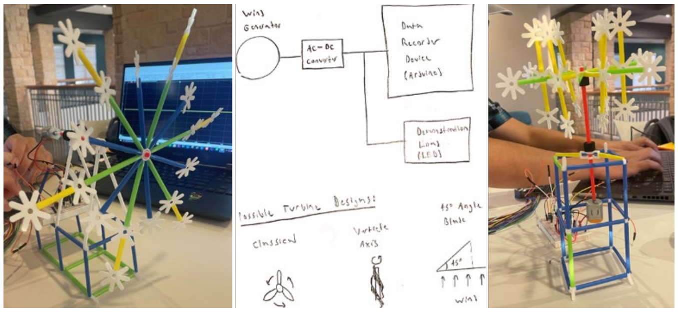
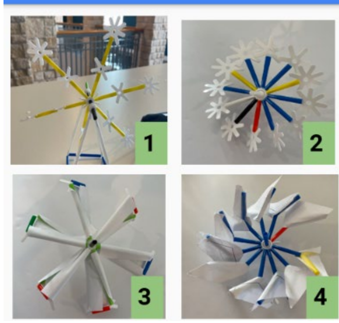


Fig. 5. The initial design sketch (middle), and first horizontal axis (left) and vertical axis (right) wind turbines

After a few iterations of design changes, the team developed different designs for each horizontal axis and vertical axis design. After that, measurements (voltages and currents) were taken to determine how the design of their wind turbines influences how much electricity in terms of power (voltage times current) they could generate. Also, they would learn the need for a gear system as the generator can use more of the rotation speed from the spinning blades to make more electricity. Some of the different wind turbine designs and the comparison of power output are shown in Fig. 6 and 7.

Horizontal Turbines

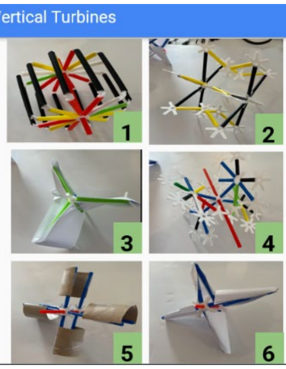


Horizontal	W/ Gear		W/o Gear	
Design #	Vo(V)	Po (mW)	Vo(V)	Po (mW)
1	0.747	2.54	0.4648	0.98
2	2.264	23.3	1.467	9.78
3	2.437	27	1.594	11.55
4	1.992	18.04	1.261	7.23

Design #	Gear:No Gear Voltage Ratio
1	1.607
2	1.543
3	1.529
4	1.58
Avg	1.565

Fig. 6. Wind turbines with the horizontal axis and comparison of their power outputs

Vertical Turbines



Verticle	W/ Gear		W/o Gear	
Design #	Vo(V)	Po (mW)	Vo(V)	Po (mW)
1	1.968	17.6	1.5173	10.46
2	1	7.18	0.7821	2.78
3	1.564	11.12	0.7603	2.63
4	1.391	8.79	0.8	2.91
5	2.556	29.7	1.345	8.22
6	2.848	36.87	1.9688	17.62

Design #	Gear:No Gear Voltage Ratio
1	1.3
2	1.6
3	2.05
4	1.738
5	1.9
6	1.44
Avg	1.671

Fig. 7. Wind turbines with the vertical axis and comparison of their power outputs

This enabled them to comprehend the information engineers require to effectively develop wind turbines. The team's learning objectives for kids are summarized below.

- Students understand the difference between renewable energy and non-renewable energy.
- Students understand the energy conversions that take place in a wind turbine.
- Students can describe the process of building a wind turbine in terms of structures and types of blades.
- Students observe how the design of a wind turbine impacts the amount of electrical energy it can generate.
- Students understand the advantages and disadvantages of horizontal and vertical wind turbines and where each is a more suitable choice.

B. *Vinette #2: Electricity Budgeting in Household*

The main goal of this lesson is to teach kids about budgeting with energy conservation. While many kids can grasp the basic ideas of budgeting, most might not know that budgeting comes in several different forms, such as with energy. It should be stated that, as with money, energy also comes with a "cost" that must be accounted for. Six appliances (fan, lights, electric stove, AC, washing machine, and EV charger) are connected through a circuit supplied with a battery bank. The distinction between the appliances is that some of them need to be turned on for long periods, such as the lights and fan, while others should be on for shorter periods, such as the washing machine. The initial sketch of the product and its final version is presented in Fig. 8.

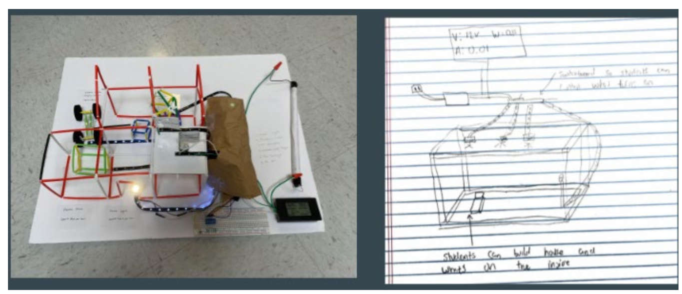


Fig. 8. The final product (left) and the initial sketch (right) of the project

The cost of running each appliance was displayed as rates as presented in Table I.

TABLE I. HOUSEHOLD DEVICES AND THEIR ENERGY COST PER HOUR

Household device	Fan	Lights	Stove	AC	Washer	EV
$ per hour	0.01	0.06	0.36	0.6	0.6	1.4

The presenter will give a simple explanation of the circuit layout and explain why this was incorporated. This concept can test students on their skills regarding decimal arithmetic and budgeting. During the lesson, students should look at this budgeting concept and think about how it applies in the real world, as shown in Fig. 7. Learning objectives set by the engineering student team for this lesson are as follows.

- Students learn that each electronic device they have at home uses a certain amount of electricity, as given by the manufacturer.
- Students know how to measure energy usage for a specific device of their choice over a certain time period.
- Students understand the difference between electric power and electric energy.
- Students know how to estimate their monthly electricity bill with an assumption of device usage per day.
- Students learn how to read their electricity bill.

Fig. 9. Engineering student outreach team demonstrating their product about electricity budgeting

V. Conclusions

For the past few years, most hands-on K–12 outreach projects have either halted or shifted to online learning due to the changed learning environment after the pandemic. While the virtual learning environment can exchange new information promptly and keep students updated with the changing world, it still lacks effectiveness. Interactive projects and in-person, hands-on learning should revive and accelerate their presence to support the student's understanding of complex concepts and processes, catch up with the rapid development in engineering and technology, and help them prepare well to be good consumers in the next generation.

A Power Research Group from Texas A&M University, a private STEM research center, and a community public school created a Power and Energy Outreach project. We are eager to create innovative curricula for teaching K–12 students about the fundamental theory of the power system to teach kids to have a critical lens on its prevalence, understand the current environmental dialogues, and become good consumers of energy resources.

Using flexible and portable STEM materials, the TAMU engineering undergraduate students created unique and interactive lessons but delivered information that responds to the current research and articles that show that students in K–12 can expand their STEM learning with their teachers at schools through engineering experts and hands-on activities that are newly spread to the U.S.

Some quotations from college engineering students' feedback, as contributors provided meaningful and unique experiences as they completed their practices as knowledge contributors in a public-school classroom: "When the kids walked through the door, we could see the excitement in their faces. The thought that this might be the first time some of them saw themselves as a science teacher was really rewarding." and "It was a unique opportunity to experience becoming a contributor for the STEM education to elementary school kids."

This research paper wishes to report on the procedures of a long-term research project and its strategies for the effectiveness of a semester-long research project. To end the study through qualitative analysis, researchers collected data from college students to demonstrate the process of task completion and various written surveys following the guided questionnaires.

Acknowledgment

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