First Year Experience from RET Site: High School Teacher Experience in Engineering Design and Manufacturing

Abstract

In 2019, University of Houston (UH) at Houston, Texas was awarded an NSF Research Experience for Teachers (RET) site grant titled "RET Site: High School Teacher Experience in Engineering Design and Manufacturing." The goal of the project is to host 12 high school teachers each summer to participate in engineering design and manufacturing research and then convert their experience into high school curriculum. In summer of 2021, the first cohort of 12 teachers from Region 4 of Southeast Texas participated in the RET program at UH College of Technology (COT). This six-week program, open to local high school STEM teachers in Texas, sought to advance educators' knowledge of concepts in design and manufacturing as a means of enriching high school curriculums and meeting foundational standards set by 2013's Texas House Bill 5. These standards require enhanced STEM contents in high school curricula as a prerequisite for graduation, detailed in the Texas Essential Knowledge and Skills standard. Due to the pandemic situation, about 50% of the activities are online and the rest are face to face. About 40% of the time, teachers attended online workshops to enhance their knowledge of topics in engineering design and manufacturing before embarking on applicable research projects in the labs. Six UH COT engineering technology professors each led workshops in a week. The four tenure-track engineering mentors, assisted by student research assistants, each mentored three teachers on projects ranging from additive manufacturing to thermal/fluids, materials, and energy. The group also participated in field trips to local companies including ARC Specialties, Master Flo, Re:3D, and Forged Components. They worked with two instructional track engineering technology professors and one professor of education on applying their learnings to lesson plan design. Participants also met weekly for online Brown Bag teacher seminars to share their experiences and discuss curricula, which was organized by the RET master teacher. On the final day of the program, the teachers presented their curriculum prototype for the fall semester to the group and received completion certificates. The program assessment was led by the assessment specialist, Director of Assessment and Accreditation at UH COT. Teacher participants found the research experience with their mentors beneficial not only to them, but also to their students according to our findings from interviews. The mentors will visit their mentees' classrooms to see the lesson plans being implemented. In the spring of 2022, the teachers will present their refined curricula at a RET symposium to be organized at UH and submit their standards-aligned plans to teachengineering.org for other K-12 educators to access.

1. Introduction

In 2019, University of Houston (UH) at Houston, Texas was awarded an NSF Research Experience for Teachers (RET) site grant titled "RET Site: High School Teacher Experience in Engineering Design and Manufacturing." The goal of the project is to provide opportunities for high school STEM teachers to engage in innovative engineering design and manufacturing

research and develop advanced high school STEM curriculum modules. The objectives are to 1) recruit a total of 36 (12 per year) high school teachers with diverse background for 3 years to engage in the engineering design and manufacturing research; 2) develop and implement innovative curriculum by translating cutting-edge research in advanced design and manufacturing from UH into high school classrooms, and meeting Texas Essential Knowledge and Skills (TEKS) standard [1,2,3]; and 3) provide interdisciplinary and hands-on experience to stimulate the interest of teachers and students in STEM.

In 2013, the 83rd Texas Legislature established the new Foundation High School Program, House Bill 5, as the default high school graduation program for all students entering high school beginning in 2014-2015. House Bill 5 requires enhanced STEM contents in high school curriculum as part of the graduate requirement [4]. Bill 5 listed four levels of high school advanced courses for graduation: Foundation, Endorsement, Distinguished and Performance Acknowledgements. The varying levels indicate the degree of proficiency of course contents in advanced STEM topics, detailed in TEKS standard. However, many high school teachers lack sufficient training to prepare these new course modules. It is imperative to build active long-term collaborative partnerships between high school teachers and UH engineering technology faculty to bring knowledge of advanced engineering to classrooms. The RET site is a timely opportunity to recruit high school teachers to gain experience in design and manufacturing and develop course modules.

The rest of the paper is organized as follows. Section 2 discusses the teacher recruitment. Section 3 discusses the RET activities. Section 4 discusses the RET program assessment for the first year. Section 5 has the conclusion for the paper.

2. Teacher Recruitment

The teacher recruitment turns out to be a process that is more difficult than we expected. In fall 2019, we have prepared the RET 3-fold flyer and set up a dedicated website for RET program[5]. The PI attempted to reach out to the local ISDs and also a few high schools directly. One of the main efforts was to talk to teachers about the purpose of the RET site program and why it was specifically designed to them. The co-PI has strong collaborative work with local ISDs and was able to reach teachers directly through her networking. Nevertheless, we did not receive many applicants although the Houston Metropolitan has a lot of qualified high school STEM teachers. In Spring 2020, 12 high school teachers were selected for the summer 2020 RET program. Unfortunately, due to COVID-19, the summer 2020 program had to be postponed to summer 2021. The pandemic was not over in 2021. It was hard for us to decide whether to hold the RET site in 2021 and the teachers are also wondering about the same question. We managed to keep 9 teachers from the 2020 cohort and recruited 3 new teachers. These 12 teachers together formed the summer 2021 cohort.

The group consists of 8 male and 4 female teachers; 1 African American/Native Indian, 5 Asian, 4.5 Caucasian, and 1.5 Hispanic. One of these teachers was recruited as Master Teacher who participated in several other RET site program at Rice University and University of Texas in

Austin. Our Master Teacher was selected because of his strong knowledge in TEKS, strong communication and problem-solving skills with a positive attitude. The role of Master Teacher was to aid other teachers in course module development and assessment, to host Brown Bag Seminars, and to host teach course development session.

3. Teacher Activities

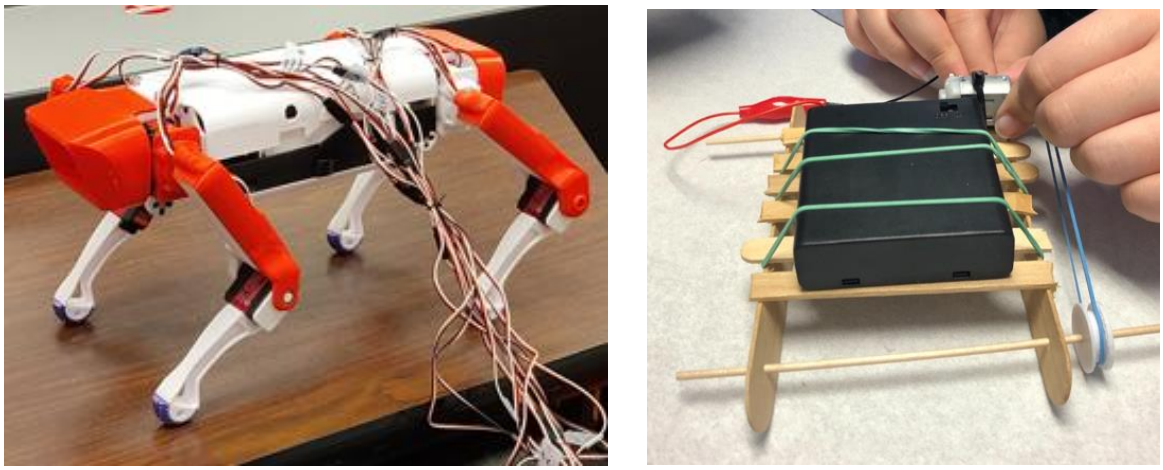
In summer 2021, the first cohort of 12 teachers from Region 4 of Southeast Texas participated in the summer research and education program from June 14 to July 23, 2021 at UH College of Technology.

The one and a half day were the orientation in which teachers were given an introduction to the RET program, introduction to faculty research topics, lab safety, general research process, curriculum development expectation, and teachengineering.org website. The teachers signed an agreement and filled 1099 form for stipend payment, tax, and IRB review purpose. A special 3-hour lab safety session was given by UH Environment, Health and Safety Program Managers. At the end of the first day, each teacher spent about two to three hours on assembling a 3D printer with assistance from Research Assistants. The first day of the orientation was on campus.

Six UH professors, Kamran Alba, Burak Basaran, Medhat El Nahas, Weihang Zhu, Francisco Robles, and Zheng Fan, each led one week of workshops. The topics of these workshops include thermal and fluids, 3D geometry modeling, finite element simulation, subtractive and additive manufacturing, material selection and energy, battery design and renewable energy, and robotics. Throughout these workshops, multiple engineering software such as SolidWorks and Ansys was adopted to teach subjects in computer aided design, finite element analysis, and computer aided manufacturing. Four professors, Alba, Fan, Robles, and Zhu, are tenure-track / tenured professors and have their own research labs. These four engineering technology mentors, assisted by student research assistants, each mentored three teachers on projects ranging from additive manufacturing to thermal/fluids, materials, and energy. The assignment of teachers to mentors were based on the background and interest of teachers as evidenced by their resumes and essays from the application process. Two examples are provided as follows.

1. Mr. K teaches robotics and algebra. He was assigned to design and fabricate a robot dog, a mini version of the Boston Dynamic Spot Mini. Mr. K is a hobbyist in electronics but has zero experience in 3D printing. Assisted by an undergraduate student assistant, Mr. K printed all the components with 3D printers, improved the electronic circuit from an open-source robot dog design, and assembled the robot to be functional by the end of the sixth week (Figure 1). After the summer, Mr. K developed a course module with toy car kits to teach algebra. He used low-cost materials to make the kits by himself. The undergraduate student assistant also developed great interest in this project which became his senior design project to improve this robot dog.
2. Mr. N teaches computer science, physics, and astronomy. He was assigned to work with a graduate student on virtual reality devices integration and application development with a

game engine. He developed the idea of comparing video game-based motion analysis with real world object motion analysis. He discovered that video game's rigid body motion does not observe physics law faithfully. As a result, he developed a set of Python and JavaScript programs to analyze the videos captured from games and real-world action. This course module is used to promote computational thinking in his introductory physics course. He presented his work in a local teacher conference and won the presentation award (Figure 2).



(a) Robot dog design and fabrication (b) Toy car design kits for teaching

Figure 1. Mr. K's summer project and his teaching kits at high school

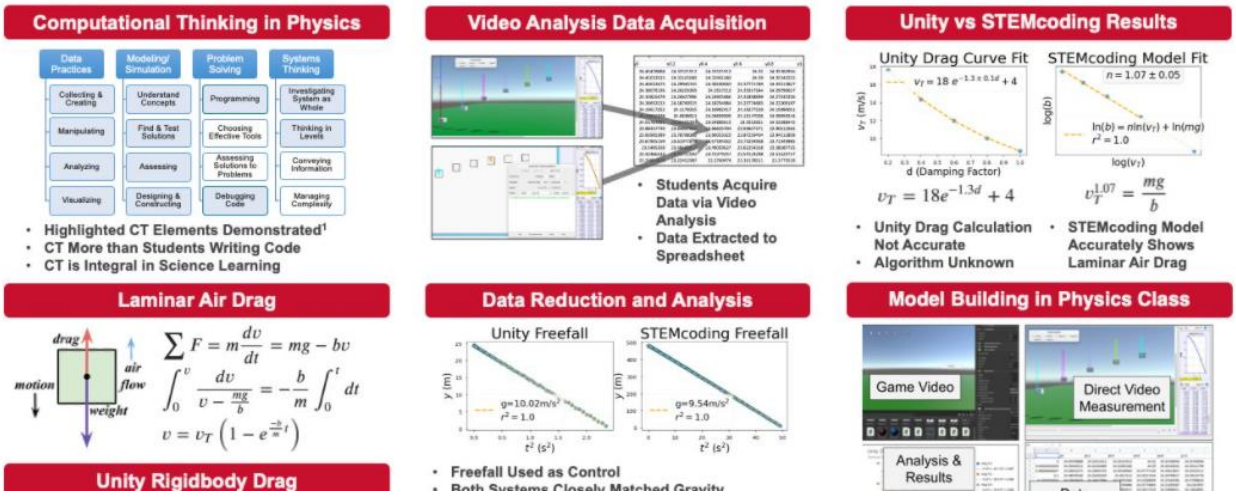


Figure 2. Mr. N's presentation on analyzing video game dynamics with computation in physics

The group also participated in industrial field trips to local companies including ARC Specialties, MasterFlo, Re:3D, and Forged Components. According to feedback, these field trips were the favorite part for some teachers, although the weather was quite hot in Texas during these trips. ARC Specialties at Houston is one of the largest robot integrators in North America.

Master Flo manufactures pumps for oil and gas industries (Figure 3(a)). Re:3D at Houston is a small business that specializes in gigantic 3D printers. Forged Components, merged with ForgeUSA a few years ago, is a traditional forging company that is now rarely found in North America (Figure 4). During the field trips, there were heated discussions on what we can do in education to really help bring manufacturing back to USA.

(a) Field trip to MasterFlo, a pump manufacturing and assembly company in Houston

(b) Field strip to Forged Components Inc., a manufacturing company in Houston

Figure 3. Industrial field trips to local companies in Houston

The teachers worked with the UH curriculum specialist Augustina Reyes, professor of education, and two UH Engineering Technology instruction track professors, Burak Basaran and Medhat El Nahas on applying their learnings to lesson plans. The teachers were split into two groups with six members in each group. Each group of teachers meet with Dr. Reyes and Dr. Basaran/El Nahas to discuss options for curriculum development. Course module templates downloaded from teachengineering.org were used to guide course module development. The teachers focused on inquiry-based learning to increase students' critical thinking, curiosity and better understanding of Math & Science. The lessons they developed included active learning for individual and small group investigations rather than simply providing teacher led presentations.

Participants also met weekly for Brown Bag teacher seminars to share their experiences and discuss curricula, organized by master teacher Mr. Jimmy Newland, Bellaire High School, Houston Independent School District (HISD). The teachers shared their progress in research and knowledge learned. In addition, every Friday morning, teachers get together through Microsoft Teams to discuss their curriculum development ideas. This cohort of teachers have rich experience in past curriculum development.

On the final day of the program, the teachers presented their curriculum prototype for the fall semester to the group and received completion certificates. The program assessment was led by assessment specialist Huda Sarraj, Director of Assessment and Accreditation at UH COT. The six engineering technology mentors will visit their mentees' classrooms to see the lesson plans being implemented. In the spring of 2022, the teachers will present their refined curricula at a RET symposium to be organized at UH and submit their standards-aligned plans to teachengineering.org for other K-12 educators to access.

Besides the official RET site website set up by the research team, a Facebook page and a LinkedIn page have been established for the RET site program to disseminate the activities information [5,6,7]. Even though the social media pages are open to public, login is required for viewing.

4. RET Program Assessment

a. Teacher Performance and Improvement

Each teacher was given one pre-program survey at the beginning of the survey and one post-program survey after the summer program is over. This cohort of teachers has an average of 15 years of K-12 teaching experience and 14 years of high school teaching experience. Most teachers come in with little knowledge about the background in the research topics. Through the workshops, they have obtained basic information in the research areas in this RET program. Then they obtained in-depth knowledge in certain fields with their mentors. Teachers reported having an average of three (3) 3D printers in their high schools, however, there is a lack of expertise needed to use these printers effectively. The RET site program offered a good opportunity for all the teachers to gain experience in 3D printing. Some teachers reported that this helps them to work with the FIRST robotics activities, as quoted below.

I had some experience with robotics from running a FIRST robotics team for a few years at my school. I didn't have any experience with 3D printing prior to last summer but am able to make 3D printed items now. The applications of this were very interesting when we visited the 3D printing company.

I didn't have any experience before doing the research program in any of these areas. I have since learned how to use CAD software and design some things myself. I also learned a lot more about manufacturing through our field trips.

The RET participants come in with diverse STEM backgrounds from various disciplines in math, physics, chemistry, biology, and CTE (Career and Technology Education). Engineering content is under CTE. Among the participants, CTE teachers indicated that they found the RET program most helpful as this was related to what they needed to teach in their pre-engineering curriculum. During the RET learning experience, the physics teachers readily found connections with some course concepts they teach and what were introduced at the RET program (e.g., finite element analyses). A few STEM teachers, however, found it hard to understand the materials, especially abstract and mathematics intensive contents, covered in the research workshops as well as the engineering technology research in the lab. Because of different personal and professional interests, some teachers were very active in pursuing research tasks while others switched gears to focus more on course module development because they felt the research was too hard to grasp within such a short period of time.

It seemed apparent that some teachers did not really 'get it' especially with the mathematics theory and software operations. A few teachers indicated that they may come back next year to strengthen the knowledge. By acknowledging the challenge of narrowing the gap between subject matters and research, one teacher suggested a better "match" between teachers and faculty mentors in terms of their subject and research areas, as quoted below.

Some of the activities were hard to implement in the classroom. Too much mathematics, a lot of differential equations, hard to implement in high schools … There was a disconnect between activities and what I can incorporate in classroom. … disconnect with my subject as I am a physics teacher, not a chemistry teacher which what most the activities focused on. … A structured and right allocation of mentor depending on the subject taught by teachers. Something that she can share to her class. In one word alignment!

b. Overall Program Satisfaction by Teacher Participants

To see the effectiveness and its impact of the RET program, we have conducted assessment through surveys and interviews to understand whether and what they have learned from the RET program. Accordingly, the teachers were asked to share their overall experience of the RET program, which included thermal and fluids, SolidWorks as an important tool for design, analysis, and manufacturing, substrative and additive manufacturing, robotics and

automation, virtual reality, material selection and energy, battery design and renewable energy. Overall, teachers found the program helpful. Below are some example comments:

> *The most important thing I took away from this was the need for students to be critical thinkers instead of memorizers of information. Also, to have hands-on experience. Many students don't enter college with basic lab skills and / or basic skills using tools. Everyone, and especially engineering students, should be able to think through basic problems to formulate a solution. They should be able to test the solution to see if it works or needs to be modified. There needs to be opportunities in school to promote independent thinking, creating, building and problem solving.*

> *The most important thing that I learned from the RET program is the wide variety of fields students can go into within the engineering area, that involve many different levels of education.*

From the survey, it is clear that many teachers have learned or improved their knowledge in the topics of Computer-aided drafting, design, and manufacturing, Finite element analysis and simulation, Sustainability and Energy, Thermal / Fluid, Manufacturing processes, 3D printing and robotics, Nanotechnology and materials, and curriculum development. Below are example comments about the connection between the research and curriculum development and future activities:

> *I will expand what I do with the kids with the 3D printer in the room. The interactions with professors will help to better advise students in the classroom especially seniors.*

> *I will implement more hands-on activities in my classroom. It is more effective than just PowerPoint presentations.*

Because of COVID-19 pandemic, the workshops were delivered online through Microsoft Teams. While it was more convenient, it was not an ideal way to deliver knowledge to teachers who hoped for more hands-on experience, as quoted below.

… a lot of highs in terms of experiences and speakers … a lot of lows because of a lot of Teams meetings could use more interactions … There needs to be more hands-on opportunities and less classroom style lecture … More time for hands-on activity during lab time would be nice.

5. Lesson Learned

For most of the faculty mentors, this was their first experience of mentoring high school teachers through the RET program. There are many lessons learned from the first cohort of the teachers. The teachers also provided their comments on improvement through an anonymous survey and interview. The lessons are classified into two categories as below.

A. For the Mentors

1) The recruitment for K-12 teachers is not easy. In addition to a good marketing job, a good understanding of teachers' mindset is important. It seems that K-12 teachers consider research to be something scholars do, rather than themselves. Therefore, even though the RET program was designed for K-12 teachers, it is necessary to explain the program clearly on a one-on-one basis.
2) Prior to the RET onset, faculty mentors have purchased lab materials and got ready for the teachers' activities. During the summer program, however, we realized that more materials were needed during the program, and it took time to get the things we needed. Therefore, for a seamless program running, a more careful purchasing planning is needed regarding necessary supply.
3) Communication between faculty mentors and teacher participants prior to the RET program start is important to discuss research tasks and the expectation as well as obtaining necessary lab materials or equipment. This will help avoid surprise or frustration during the program.
4) Mentors should get familiar with the workflow of the RET program, especially for the first year of the program in order to avoid unexpected surprises.
5) For the success of the program, there are a lot of things to be prepared. It should be noted that the preparation is not just limited to teaching and researching. For example, the PI had to make arrangements with IT account setup, parking, stipend payment procedure, and sometimes with Wi-Fi services on campus.
6) It is important to design a tailored set of survey questions and more carefully design interview questions in order to gain more understanding of impact of RET site on teachers.

B. For RET teachers:

1) Getting a good curriculum specialist can greatly help teachers in preparing their course modules. It is necessary to keep the communication channels between mentors and curriculum specialists to tune the research tasks. In the weekly teachers' conferencing call, the teachers were given a half day to meet together, share their research experience, and discuss how to convert their experience into curriculum.
2) The psychological changes of the teachers must be considered and watched during the progress of the RET program. Research tasks may need to be tailored to be compatible with teachers' backgrounds to be more relevant and meaningful. It is also helpful to ask teachers to help each other.
3) Teachers enjoyed the field trips very much and considered them as the critical components of the summer research to get real world engineering experience.

6. Conclusion

The 3-year project started in 2020 but was postponed for the whole year due to the pandemic. It is currently in its second year of operation. Amidst the pandemics, as part of the

academic year follow-up activities, we have visited a few teachers in their high school curriculum and saw how some course modules are implemented in the classroom.

Figure 4. A High School visit by UH Professor El Nahas

The project has been running smoothly in the summer 2021 program. There is a list of lessons learned from this past summer. A few important changes we are going to implement for the second cohort will include:

1. Plan early and match teachers and faculty based on their mutual interest.
2. Define research tasks more clearly for teachers before the summer starts and make sure both teachers and faculty mentors understand the expectation.
3. Reduce the number of workshop days and increase the number of in-lab activities as we expect the pandemics situation will be ameliorated over time.
4. Define a better set of survey questions and interview questions.

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