



Application of 3D CAD and 3D printing to RET Program to Enrich Engineering Design Education

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Children (WCGTC), serving as their executive administrator, and editor of Gifted International from 1980-1990. She has conducted training sessions throughout the United States and internationally. Dr. Sisk is author of *Creative Teaching of the Gifted*, and *Making Great Kids Greater*; coauthor with Doris Shallcross of *Leadership: Making Things Happen*, *The Growing Person*, and *Intuition: An Inner Way of Knowing*; coauthor with E. Paul Torrance of *Gifted Children in the Regular Classroom* and *Spiritual Intelligence: Developing Higher Level Consciousness*; coauthor with Susan Israel and Cathy Block of *Collaborative Literacy: Using Gifted Strategies to Enrich Learning for Every Student*; and co-author with Michele Kane of *Planting Seeds of Mindfulness*. In addition, she has contributed numerous articles and chapters in books on gifted education.

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Abstract

After the successful operations of Research Experience for Teachers (RET) for two years, at Lamar University (LU), we made two major enhancements in the 2019 RET summer program: 1) to have workshops and research activities that are centered around the 3D CAD design and 3D printing, which are now readily available in most high schools, and we already made great impacts on the design and manufacturing education; 2) to put more emphasis on the connection between the design and manufacturing research experience with the high school STEM course module development so that the participating teachers would not only have more hands-on research experience, but also be able to kick-start the development of the suitable course modules for their students. The goal of the project was to host 12 high school teachers to participate in engineering design and manufacturing research and then transfer their experience into high school curriculum.

1. Introduction

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 [1]. House Bill 5 requires enhanced STEM contents in high school curriculum as part of the graduate requirement⁴. 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.

In 2016, Lamar University (LU) at Beaumont, Texas was awarded a National Science Foundation (NSF) Research Experience for Teachers (RET) site grant titled “RET Site: Incorporating Engineering Design and Manufacturing into High School Curriculum.” The goal of the project was to host 8-12 high school teachers each summer to participate in engineering design and manufacturing research and convert their experience into high school curriculum. In the past three summers, 31 high school teachers have participated in engineering design and manufacturing research and then transferred their experience into high school curriculum. This

year, more information is on the project website and the Facebook group [2, 3] than previous years.

The rest of the paper is organized as follows. Section 2 discusses the teacher recruitment Section 3 discusses the RET program overview and the incorporation of 3D printing in the workshops. Section 4 discusses the course modules developed that used 3D printer as a tool. Section 5 has the conclusion for the paper.

2. Teacher Recruitment;

In summer 2019, the third cohort of 8 teachers were selected to participate in the research and education activities in the College of Engineering at LU. The group consists of 4 male and 4 female teachers; 2 African American, 1 Asian, and 5 Caucasian. One of them is designated as Master Teacher to help coordinate the summer activities. The master teacher has prior experience in participating in the RET program in summer 2018. The role of the Master Teacher was to aid other teachers in course module development and assessment, to host Brown Bag Seminar, and to co-organize one-day teacher conference.

The teacher recruitment was more challenging than we anticipated. We planned to recruit 12 teachers but was only able to accept 8 among those who met the criteria. We have prepared the RET 3-fold flyers and setup a dedicated website for the RET program. The PI gave a presentation on the RET site program in the Area 5 Mini-CAST conference hosted by Science Teachers Association of Texas for Texas Region 5, where LU is located as the only four-year university. Even though some teachers expressed their interests, many did not apply even after the PI followed up with invitation emails. The PI, Co-PI and senior personnel faculty members visited some high schools in person and talked to teachers about the purpose of the RET site program and why it would be beneficial to them and persuaded the teachers to apply for the program. Regarding this recruitment challenge, teachers shared their thoughts which is described in the program result section.

3. RET Program Overview

The first two days were the orientation in which teachers were given an introduction to the RET program, lab methods, safety, general research process, curriculum development expectations, and engineering lab tours. The teachers signed an agreement and filled 1099 form for stipend payment, tax, and IRB review purpose. Five LU engineering professors provided morning workshops on six subjects and various research projects. In the first week, we started with the 3D CAD design using Autodesk Fusion 360, which is powerful and popular CAD software commonly used in engineering design. In the following weeks, the teachers had opportunities to see the applications of the CAD and 3D printing that were imbedded in the following research projects guided by the LU professors:

- Dr. Liu offered workshops on computer integrated manufacturing systems, focusing on bridging the gap between design and manufacturing, taught the teachers how to use the same CAD platform Autodesk Fusion 360 to create cutting tool paths for CNC machines in order to manufacture the 3D CAD design. The topic of converting the 3D design file into a STL file format and feed into a slicing software to prepare the CAD design for 3D printing was also covered.

- Dr. Brake led the teachers design a magnetic concrete mix that was used to manufacture a concrete CI core transformer for application in wireless power transfer systems. This work included drawing and printing 3D models to make casting molds for concrete casting. Designing and testing concrete CI cores under 60 Hz AC sinusoidal excitation to determine the dynamic magnetic hysteresis of the concrete transformer. This work could be implemented into a Physics course or an engineering course that places focus on interdisciplinary activities that include multiple disciplines working together- both civil and electrical engineering.
- Dr. Fan taught teachers design and 3D printed standard tensile specimen and use the specimen to test the tensile strength of the 3D printed materials. Various 3D printing conditions such as print direction, fill density, etc. were used to study the impact of the 3D printing conditions on the achievable strength of the 3D printed parts.
- Dr. Zhou led the project on synthesis and manufacturing of robots with legged walking mechanisms after delivering workshop on mechanism design and robotics. The workshops start with mathematics foundation for mechanism. Teachers were fascinated by how high school Geometry and Algebra knowledge can be applied to design a simple machinery.
- Dr. Li' workshops were on alternative and renewable energy, which covered three most important renewable energy resources: hydroelectric power, solar power and wind power. This is the only subject area where CAD and 3D printing was not directly used. Yet energy is very important aspect in engineering field because no manufacturing is possible without energy. The workshop was to broaden the participating teachers' horizon on the grand energy challenge the entire world is facing and will continue to face.

Each week, the teachers worked with the LU curriculum specialist Dorothy Sisk, who is professor of teacher education, on applying their Engineering research into lesson plans. The teachers were split into two groups and meet with Dr. Sisk 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 learning activities for individual and small groups experiments rather than simple presentations led by teachers. The lesson developments were compliant with the Texas Essential Knowledge and Skills (TEKS) standards [4,5,6].

In addition, to facilitate the ultimate goal of creating high quality course modules for the RET teachers, we implemented the following major improvements in summer 2019 based on the feedback from the first two RET cohorts:

1) Weekly teachers' meetings for course module development. Past two cohorts expressed difficulties in converting research experience into suitable course modules. For example, a chemistry teacher may participate in research that does not involve much chemistry. Another issue raised by teachers who may not know what they are expected to teach in the coming semester or academic year because of teaching duties that change based on their campus needs. In order to address such challenges and to facilitate collaboration, teachers were arranged to spend Friday mornings together to exchange course module development ideas and share their interpretation of learned knowledge.

2) Lab rotation among mentors for teachers and facilitate collaboration among mentors in coaching and research. The mentor assignment was made before the program launch. But at the end of the orientation, we made some changes based on the teachers' feedback and preference for a better fit. This was to allow teachers to have exposure to various research activities. Each teacher worked with at least two, most with three LU faculty mentors during the 6-week program.

3) Each teacher assembled a 3D printer and took it back to high schools. Some teachers came from economically disadvantaged schools. They need equipment to support their course module development and introduce the state-of-the-art technology to their students. Through assembling a 3D printer, each teacher improved their hands-on skills and self-efficacy in providing guidance to their own students.

The teachers also participated in field trips to local companies including C&D Robotics, Metalforms (heat exchanger repair and maintenance), Optimus Steel (Steel mill), and American Valve & Hydrant, to name a few.

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, Julia Yoo, who is associate professor in the department of educational leadership at LU. The first cohort shared their experience in a local teacher conference in February 2018. Most of them have completed the course development. Some course modules were published by teachengineering.org. Two conference papers have been published on the LU RET site. The first paper was presented in the conference of ASME/MSEC & SME/NAMRC at Texas A&M in June 2018 [7]. This paper was focused on the design and manufacturing education content. The second paper was presented in the ASEE annual conference at Salt Lake City in June 2018 [8]. This paper was focused on the RET program plan, execution, and assessment.

4. High School Course Modules Developed with the aid of 3D printing

All teachers were instructed to find the requirement and rigor needed for the course module development from the teachengineering.org. As part of the RET agreements, a teacher needs to get her/his course module approved before course development fee is paid to her/him. This serves as the gate keeper and incentive for completing a high-quality course module. While many teachers have submitted their course modules to teachengineering.org, only three of them have been approved so far. Below, we briefly explain the approved modules.

Module 1: Maker Challenge: Simple Machines and the Rube Goldberg Challenge

This course module was developed by a high school math teacher in Clute, TX. The module was designed for Grade 10 in Physics and/or Science and Technology subject areas. The objective is to teach simple machines and mechanisms through a hands-on project. The development of the course module was inspired by the RET experience of the application of 3D printing in design and manufacturing.

The estimated time required for the module is 225 minutes. The module starts with a 15-minute introduction followed by a 5-minute video "OK Go-This Too Shall Pass-Rube Goldberg Machine" on Youtube. Students are then divided into teams of three or four to perform an initial research activity and plan their device (20 minutes). Then, a teacher can suggest a planning

component and have students sketch their design in advance of building. It is important to engage them in the five-step design cycle: ideate, create, test, iterate, and share. Students will research simple machines and other mechanisms as they learn, and make Rube Goldberg machines. The simple mechanisms include lever, wheel and axle, pulley, inclined plane, wedge, screw, etc. The next step is Maker time (135 minutes). By working in teams, students design and build their own Rube Goldberg devices with 10 separate steps. In addition to the use of readily available classroom craft supplies, 3D printers can be used to design, and print one or more device mechanisms. Finally, during the 45-minute wrap up time, a teacher can have teams demonstrate their device in a gallery-style presentation. The students will record their challenges and successes in notebooks or design journals.

After this challenge, students should be able to 1) identify different types of simple machines and mechanisms; 2) explain the nature of a Rube Goldberg machine; and 3) Recognize the use of mechanisms in everyday life. Students love this open-ended, team building project with great potential for creativity. The course module was developed by the following educational standard: TEKS for CTE-130.414(c)(7)(C) and ITEESA-Design (8).

Module 2: Shake and Rattle

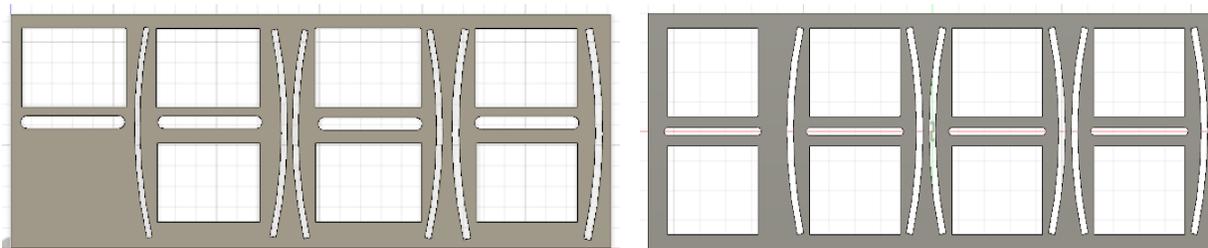
This course module was developed by a science teacher in Richmond, TX. This module was designed for Grade 12 regarding teaching simple harmonic motion in the subject areas of Science and Technology and/or Physics. This course module also incorporates the 3D printing in student activities.

In the module learning activity, students simulate the effect of an earthquake to a vertical structure. A 3D printed shake table represent ground movement. The vertical structure representing a skyscraper is constructed using balsa wood connected by Styrofoam balls. Students can design and construct this structure with minimum oscillation from a varying simulated earthquake intensity. Furthermore, the aforementioned vertical structure must not fail at maximum shake table movement. The course module starts with a refreshing review about important concepts in oscillatory motion and vibrational damping by introducing students to their engineering challenge, and/or any constraints/goals for their designs, such as minimum 2-foot 3-stories constraint. Students are then asked to form team of three to design and construct their vertical structure with balsa wood and Styrofoam balls. The students need to figure out how they can minimize the displacement of their structure from its neutral position. The design/building goal is to have the tallest vertical structure to survive the shake test. Each design trail can be tested with the 3D printed shake table. Students are encouraged to redesign their structures to minimize the displacement from neutral. Teams are also asked to make actual measurements on structure height, vibration period, etc.

It is a fun activity which could strengthen the engineering connection to relating science and/or math concepts, since students act as structural engineers when they design, test, and redesign their structures. At the end of the activity, students are expected to be able to 1) calculate the period and frequency of an oscillatory motion, 2) design and construct a vertical structure under vibratory motion, 3) predict and identify the proper location of a damper for an object undergoing vibration. The course module was designed by meeting the following educational standards: ITEESA-Technology (2).

Module 3: Dimension Analysis for High School Chemistry and Physics (Activity)

This course module was developed by a high school chemistry teacher in Port Neches, TX. The aim of the module was about teaching dimensional analysis in the subject areas of Chemistry, Physical Science and Problem Solving. This course module utilizes two templates that were 3D printouts as shown in the Figure 1. Dimensional analysis is a critical concept used in all sciences, mathematics, and engineering classes. The templates were created to help students see exactly where to place steps. They were designed to fit on a class set of 9" x 12" dry erase whiteboards. This learning tool can be used for class warm-ups and hands-on activities for students. It can also be scaled down to fit in an interactive notebook.



(a) One given

(b) Two given

Figure 1 Dimensional Analysis Templates - 3D printed

Before the activity, the graphic in Figure 2 shows how shapes can be used to ‘cancel out’ undesired shapes will be handed out to students to serve as a quick warm-up tool to help illustrate the process of dimensional analysis. Teachers can have students look for patterns and discover that units on the top cancel with units on the bottom, using symbols instead of units.

Dimensional Analysis Warm-Up

1. $\text{orange circle} \times \frac{\text{blue square}}{\text{orange circle}} \times \frac{\text{yellow triangle}}{\text{blue square}} = \text{yellow triangle}$

2. $\frac{\text{red circle}}{\text{green star}} \times \frac{\text{green star}}{\text{purple lightning bolt}} \times \frac{\text{purple heart}}{\text{red circle}} = \frac{\text{purple heart}}{\text{purple lightning bolt}}$

Look at problem 1 and 2. Describe a pattern that you notice.
Use this pattern to answer problem 3 and 4.

3. $\text{brown star} \times \frac{\text{black diamond}}{\text{brown star}} \times \frac{\text{orange circle}}{\text{black diamond}} = ?$

4. $\text{blue square} \times \frac{\text{target}}{\text{blue square}} \times \frac{\text{smiley face}}{\text{?}} = \text{smiley face}$

Figure 2: Dimensional Analysis Warm-up (showing how colors and shapes can be used to mimic the dimensional analysis process)

To begin the activity, the teacher will have the students get a whiteboard, a dry erase marker, a template, and a handout explaining how the template can be used for dimensional analysis in a way similar to the symbol cancellation in Figure 2. The teacher will go over an example and ask students to work in a group on this activity.

5. RET Program Assessment Results

To see the effectiveness and its impact of the RET program, we have conducted assessment through surveys, interviews and observations with teacher participants. For the 2019 LU RET program, a total of 8 teachers (63% White/Caucasians, 25% African American and 13% Asian/Pacific Islander) participated and they came with diverse STEM backgrounds from various disciplines, such as biology, math, physics, and chemistry. Among the participants, (60% male; 40% female), the average K-12 teaching experience was 15.5 years (SD = 6.7; range 5–25). One teacher participant returned from last year's LU RET program as a master teacher.

When asked about the most important thing that they have learned from the RET program, regardless of the teacher participants' subject areas that they teach, the majority said learning about the CAD program, being able to actually design items with Autodesk Fusion 360, and to use 3D printer. Two participants said curriculum development by applying the learned knowledge. Below are example comments:

I have learned how to use Autodesk Fusion 360 to design and analyze an object. I have learned how to setup and use a 3D printer. – from a male high school math/physics teacher.

From the RET program I learned how to develop a curriculum that can be used in my classroom for the years to come. Also, I learned from the different teachers on the things that they do in their classroom so I was able to get some ideas that I can use. – from a male high school physical science teacher

Clearly, along with the CAD program design and 3D printing knowledge, teacher participants value the understanding of the research process. As the most important takeaway, a female high school chemistry teacher said,

I learned how research is done. I had the opportunity to work with a new professor and learn about their research and how it relates to 3D printing.

From a follow-up survey conducted about six months after the RET experience, five RET participants responded. Of the five, four teachers said that they implemented their learned experiences from the RET into their teaching. The implementation ranges from using scavenger hunt activities for Free-Body diagrams developed during the RET to writing and winning a \$1,000 technology grant to purchase a 3-D printer and supplies by utilizing modules and activities developed during the RET.

However, from the focus group interview, we found that the part about understanding research had mixed thoughts. Teacher participants who valued and appreciated the importance of it were those who had strong physics or engineering backgrounds or who had more understanding of the RET program with experience. Even though all teachers value their research experience, two teachers said that they really wished the RET program was specifically tailored to high school teachers with hands-on activities so that they could just take it to their classrooms and start implementing it from “day one.” One teacher participant, in particular, expressed frustration with some research portion of the RET program. During the interview, the teacher said that if he or she had known about the depth of research, he or she would not have participated in this program albeit beneficial. Being a teacher for students from underserved

populations, he or she expected more practical strategies that could be used in the classroom right away.

This challenge of translating research experience into their own subject areas seemed to be shared by those who taught chemistry, biology or mathematics that are in the realm of pure science rather than applied science, especially when they teach in the mid to low socioeconomic status areas where students often lacked prior knowledge in the discipline. As much as it was challenging to RET teachers, sharing the research experience seemed to not to be easy for RET faculty mentors. Engaging RET teachers in the research activities was raised as most challenging task by the participating faculty mentors. More specifically, faculty described that “trimming” lectures and tying the engineering experience with the STEM course module developments were the most challenging parts in the program. So, the difficulty lied in translating research engineering into something RET teachers could understand better in the given timeframe. Two RET faculty mentors especially presumed that the difficulty was due to the gap of between the engineering centered curriculum at the RET program and the background knowledge or teaching subjects by many participating RET teachers.

Another challenge teacher participants shared during the focus group interview was committing time for their learning during the summer. Many teachers postulated that recruiting teachers during the summer would not be easy because either they typically have other professional development commitments, or it would be the only time that they could spare with family for vacation. In fact, we had one teacher who wanted to apply and participate in LU RET, but eventually decided to take a break to spend time with family. This time commitment also affected RET participants’ lesson development for publications. Once they leave the program, teacher participants seem to struggle to find time to work on course modules and it becomes especially difficult if they get teaching assignments on their campuses that are different from what they worked on during the summer.

Despite the challenge of fully understanding the process of Engineering research and implementing the knowledge into their own curriculum, overall, teacher participants expressed their increased understanding of research in the field of engineering accomplishments with their CAD program design and 3D printing skill sets. In the follow-up survey, one RET teacher stated that he recommended engineering career to his students by introducing industry partners and training programs. Additionally, teacher participants found the program helpful by networking with fellow teachers and university faculty who actively conduct research. A male high school math/physics teacher said,

I have established important contacts with the faculty at the university that will enhance my career in education.

Indeed, teacher participants actively shared ideas during the learning process and the discussion often expanded to exchanging lesson activity ideas with trials and errors and sharing how to effectively teach certain engineering concepts in their classrooms.

6. Conclusion

As described in the study result section, there are many lessons learned through the LU RET program, which is designed to enhance K-12 teachers’ research knowledge in engineering

to ultimately cultivate K-12 students' passion and enrich their knowledge for science and engineering. This is a very rewarding, yet challenging task for both RET teacher participants and faculty mentors, especially in the process of translating the research experience. Having a variety of learning activities through lectures, lab experiments, field trips, working with peers seem to be helpful for RET teacher participants. The project is expected to have a sustained impact on STEM education in local high schools in southeast Texas and the Gulf Coast. The RET support is especially critical for the education and outreach in the large surrounding school districts whose minority populations average 72.5%, and 64.8% of students are considered to be economically disadvantaged. The use of 3D printing in design and manufacturing was successfully introduced into the high school STEM course development.

Acknowledgements

The project is sponsored by the National Science Foundation grant #1608886. Their support is greatly appreciated.

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