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Texas Pre-freshman Engineering Program Challenged Based Instruction Curriculum Development and Implementation (RTP, Strand 5)

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Abstract

The Texas Pre-freshman Engineering Program (TexPREP), founded in 1979, is a 7 week-long, 4 year summer program that provides academic training, mentorship, and hands-on experience for middle and high school students that are interested in pursuing STEM careers. A series of new courses that are to be offered as standardized courses at participating TexPREP institutions throughout the state are being developed by undergraduate engineering students.

Nine undergraduate students majoring in mechanical and civil engineering and computer science were hired to write the TexPREP course curriculum with the idea that students would be able to develop course content that the participants could easily relate to. Following development of the curriculum, undergraduate students actively participated in the implementation and review process. The primary teaching methodology of the courses is Challenge Based Instruction (CBI) because of its proven effectiveness over traditional lecturing. The course subjects developed included Water Science, Computer Aided Design (CAD), and Systems Modeling. All three courses were administered to returning TexPREP fourth year students.

At the beginning of each course, students were given the challenges of building a Stirling engine using items that can be found at home, designing and constructing a solar car, and creating a water theme park for the Systems Modeling, Computer Aided Design (CAD), and Water Science courses respectively. They were then guided through a series of lectures, mini projects, and assessment exercises to help them obtain the necessary knowledge to complete their challenges. The interactive and appealing nature of the courses and their respective challenges was expected to result in increased participation, improved academic performance, and greater self-motivation of the participants compared to their overall performance during the prior three years of participation in the program. Students and instructor surveys were used to help determine the effectiveness of the curriculum and pedagogy. The paper discusses the impact on the TexPREP and undergraduate students involved in curriculum development and the process for successful implementation.

Introduction

Summer outreach programs offered at colleges and universities are a means for both recruiting and preparing prospective engineering students[1,2]. These summer programs which vary from a single week to several months provide students with an early opportunity to experience college life as a STEM student. Such an experience may include exposure to engineering research and student lab facilities, interactions with engineering faculty and students, an opportunity to develop a passion for engineering and a stronger foundation in fundamental engineering skills.

One such outreach program is the Texas Pre-Freshman Engineering Program[3] (TexPREP). The

TexPREP program was founded in 1979 as a means to reach out to underrepresented minorities in engineering and other STEM fields. Students participate in the seven week summer program for up to four years spanning their middle and early high school years. There are currently over 30 TexPREP programs in Texas serving approximately 4000 students each year. The curriculum at each site is standardized to facilitate the awarding of high school elective credit for each year that a student successfully completes. Students take five courses per year that focus on STEM including Introduction to Engineering, Logic, Computer Science, Algebraic Structures, Introduction to Physics, Problem Solving, Introduction to Probability and Statistics, Technical Writing, and Seminar. In addition to the coursework, students are actively involved in a number of projects/competitions throughout the summer including miniature catapults, bottle rockets, and a robotics competition. Many of the projects are incorporated into the curriculum to provide students with a practical context for the course content. Follow-up data (summarized in the TexPREP annual report) on students who participate in the program shows that participants are more likely to attend college and major in STEM than their peers.

Prior to 2011, the curricula for the first three years of the program were well standardized however, the fourth year curriculum varied greatly from site to site and was not offered at a majority of the TexPREP sites. As part of an effort to encourage and equip sites to offer a quality fourth year to the program, a proposal was submitted to the Department of Defense. The ongoing four year grant[4] directly supports the development and implementation of new fourth year curriculum at three of the largest TexPREP sites. The developed curriculum has been made available to all sites and teachers from around the state have been provided training on using the new curriculum.

Challenge Based Instruction

The development of new curriculum for the program offered an opportunity to review the pedagogy and consider new research on effective teaching strategies. The program has had a long history of success through integrating projects into the curriculum. In year-end surveys, participants often cite the projects and associated competitions as the highlight of the summer. There are several proven pedagogies that use projects as an integral part of the instructional process such as Problem Based Learning[5] (PBL), The Five E's[6] (Engage, Explore, Explain, Elaborate, and Evaluate), and Challenge Based Instruction[7,8,9] (CBI). Although there are differences in the methods, especially in areas of emphasis, they are all inquiry based methods that rely on a constructivist or learner centered approach. Although implementation may vary greatly for each method, CBI makes use of traditional pedagogies (classroom lectures, assigned reading, in class exams) but restructures their delivery to support a learner centered approach. As a bit of a hybrid in this aspect, CBI may provide an easier transition for students and teachers while still seeing the benefits in student learning from an inquiry based pedagogy[11]. The method of CBI is to present students with a well-designed instructional challenge first and then provide a learning environment that supports students in their pursuit to address that challenge. In theory, students will understand their need for the instructional content before they receive it. The carefully crafted challenge must therefore pull in a majority of the course content as students attempt to address the challenge. CBI is not solely learner centered but a balanced approach that is assessment centered (formative and summative), knowledge centered, and community centered[10]. An effective implementation of CBI is the STAR Legacy cycle[11] which guides students through six phases entitled The Challenge (problem definition), Generate Ideas (brainstorming), Multiple Perspectives (open inquiry), Research and Revise (guided inquiry, lecture, textbook), Test Your Mettle (formative assessment), and Go Public (summative assessment, presentation).

A decision was made to use CBI as the framework for the development and implementation of the fourth year curriculum for the outreach program. The decision was based on the previous success of integrating projects into the curriculum in the TexPREP program and studies showing positive results, especially in self-efficacy and adaptive expertise[12], associated with the implementation of CBI. The development of four courses using CBI were proposed and have been implemented over the past several years. Additional CBI courses are currently being developed that will serve as elective courses based on the needs and interest of individual sites. Feedback from students and instructors has been used to revise course content.

Curriculum Development

One of the objectives of the proposal was to develop curriculum that instructors could successfully use without requiring excessive training or expertise in each of the course content areas. Instructors vary from site to site but are primarily middle and high school teachers. Some sites employ university instructors and graduate students as teachers. A number of graduate and undergraduate students were employed through the grant to assist with curriculum development and instructional support. As part of this group, nine undergraduate students were hired to help in the development of five CBI courses. The students were directly supervised by a graduate student under the direction of an engineering faculty member. The courses included Computer Aided Design, Water Science, Systems Thinking, Nanotechnology, and Computer Science.

The students had access to previously developed curriculum and TexPREP instructors who had taught similar content in prior years. Their objective was to develop and support an effective CBI challenge for each course that was engaging for students and addressed the majority of course content. Developed materials supporting the CBI challenge included detailed course outlines and learning objectives, classroom presentation slides for each day (total of 24 hours of instructional time per class), supplemental instructional videos (training students in the use of engineering software), formative (online self-assessment) and summative assessments and solutions, and a supply of project materials related to CBI challenges.

Students met weekly with an engineering professor and a mechanical engineering graduate student throughout the spring semester prior to summer implementation of three of the courses (Computer Aided Design, Water Science, and Systems Thinking). The students worked in pairs on each course approximately 10 hours per week. Each week students presented their work to the other teams and critiqued one another's work. Toward the end of the semester, the summer TexPREP instructor for the three courses met with the students to provide feedback and further refine the curriculum.

During the summer offering of the CBI courses, the student development team regularly observed each class making note of the TexPREP student's attitudes and learning and the instructor's delivery of CBI course content. Throughout the summer the curriculum development team continued to revise materials based on feedback from classroom observations especially relating to the CBI challenge. Course materials were posted online for use by other sites and the development team offered assistance to other sites using the materials. An outline of the CBI challenge and how the challenge supported course content for the systems thinking and water science courses are shown in Tables 1 and 2. The CBI challenges for the other courses are listed in Table 3. The computer science was not completed and is currently under development for implementation in 2015.

Table 1: Challenge and Outline of Systems Thinking Course

Systems Thinking Challenge: Model and build a functional low temperature difference Stirling engine from everyday household materials	
Weekly Module Content	Connection to CBI Challenge
1. Systems Introduction and Basic Theory	The term *system* is introduced to students in the context of a Stirling engine
2. Introduction to Modeling	The Systems Thinking Problem Solving Process is used to study the model of a Stirling Engine as a system
3. Introduction to Computer Modeling using Vensim	Vensim software is introduced and several systems are assigned to help students gain the skills needed to model a Stirling Engine
4. Basic Engine Fundamentals and Theory	Students are required to find the three basic types of stirling engines, describe the parts that compose them, and explain how they actually work
5. Stirling Engine Fabrication & Data Collection	Final construction and testing of an actual Stirling engine made of everyday household materials
6. Stirling Engine Analysis and Presentation	A final presentation is assigned to students to present the analysis and conclusion from their Stirling Engine project

Table 2: Challenge and Outline of Water Science Course

Water Science Challenge: Create a new water park to be built a few mile from your home. The water science theme park should be ecofriendly, educational, and fun	
Weekly Module Content	Connection to Challenge
1. Introduction to water cycle and water properties	Water cycle project demonstration at the beginning of the course.
2. Watersheds and their functions	Activity in google earth
3. Controlling water/ power development	Dam construction
4. Fluid mechanics; pumps, open channels flow	Non-Newtonian Project
5. Water treatment	Water treatment filtering project
6. Water system park	Creation of a water park

Table 3: CBI Challenges for other Developed Courses.

Developed Course	CBI Challenge
1. Nanotechnology	Develop a new multi-million dollar idea using nanotechnology (research plan, technical publication, patent application, marketing analysis, and business plan)
2. Computer Aided Design	Design and build a solar powered car that can transport you safely around campus (use of solid modeling software for conceptual design, analysis, and construction of working drawings)
3. Computer Science	Build and program a balancing robot that can pick up and transport items to you within your home (Arduino programing, i/o, and logic)

The objective of the curriculum development team was to create curriculum for high school students involved in a summer program that would prepare and inspire them for undergraduate studies in engineering and other STEM fields. Undergraduate students pursuing a STEM degree were selected to develop the curriculum for a variety of reasons including the following:

- The undergraduate students would grow in their understanding of engineering as they communicate basic engineering concepts in the courses they develop.
- The development team would be introduced to a new pedagogy (CBI) that may influence them as future teachers.
- Undergraduate students may have an advantage in inspiring those who are closer to their peer group than professors or curriculum development specialists would be.
- Grants provide significant undergraduate student support and opportunities for students to interact with faculty.
- Previous undergraduate students who have served as mentors in the outreach program have matured in their own educational pursuits.

Success for the undergraduate development team cannot be completely separated from the success of the TexPREP students and how they responded to the developed curriculum. Their hard work throughout the year to develop curriculum with innovative CBI challenges would ultimately tested upon implementation and the measured impact on the TexPREP students.

Impact on TexPREP Participants

The curriculum development team met with the instructor throughout the semester and visited the classroom regularly to observe the effectiveness of the course content and make modifications as necessary. Throughout the semester both the student curriculum development team and the course instructor repeatedly expressed a positive attitude to the TexPREP program director about the course content and receptivity of the participants to the CBI courses. Although the TexPREP students were used to doing projects throughout the summer this was the first summer that they were introduced to a more formal presentation of CBI.

Four participants dropped out in the first week of the program for various reasons which is not unusual. Of the remaining 27 TexPREP students in the course, all of them completed their courses with a cumulative score of 70% or higher. Several of the 4th year TexPREP students were also taking one or two courses at the university for college credit through the concurrent enrollment program. Over half of the TexPRE students in the program would be first generation college students if they attend college. The makeup of the class by gender was 5 females and 22 males. All were rising high school juniors or seniors.

A survey of the TexPREP student's perceptions of the 4th year CBI curriculum was developed and delivered to students during the final week of the program. All students participated in the end of course survey shown is Table 4. Results of the survey are shown in Figures 1 and 2. Responses of Agree and Strongly Agree were grouped together as well as Disagree and Strongly Disagree since the sample size was relatively small. In looking at the data for a positive impact based on the implementation of CBI, the correlated expected response was Agree or Strongly Agree. These questions were not grouped together on the survey but are grouped together in Figure 1. Questions where a negative response was expected are grouped together in Figure 2. The results show a mean response to each question favoring agreement to the positive questions and disagreement on negative questions. The strongest neutral response, Question 15, may be misleading since many students had already made decisions to pursue a STEM discipline prior to their 4th year. Only 4 of the 27 TexPREP students indicated that they expected to pursue a degree outside of the STEM disciplines.

Table 4: End of Course Survey for 4th Year TexPREP Students

Questions 8 –19: Please answer the following questions by picking the number which best describes your opinion: 1-Strongly Disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly Agree
8) Compared to the previous 3 years' TexPREP programs, I rate the 4th year TexPREP program as the most enjoyable one.
9) The program did not change my level of interest in STEM (Science, Technology, Engineering, Mathematics) disciplines for college.
10) Working together with classmates on projects and assignments helped my learning a lot.
11) Compared to the knowledge that I obtained from the previous years' TexPREP programs, the knowledge I gained in this 4th year TexPREP program benefits my understanding and interests of STEM the most.
12) The projects and/or assignments helped me apply my previous knowledge that I attained in lecture.
13) This 4th year TexPREP program did nothing to enhance my learning.
14) Compared to regular classes in my school, the 4th year TexPREP program with projects and assignments is more enjoyable.
15) This program has motivated me to study a STEM discipline in college.
16) I found that the projects and/or assignments were confusing.
17) I found that the projects and/or assignments were not related to the knowledge I learned from lectures.
18) I do not like the 4th year TexPREP program.
19) Compared to my regular school classes, this 4th year TexPREP program is more beneficial to my understanding and interests in STEM.

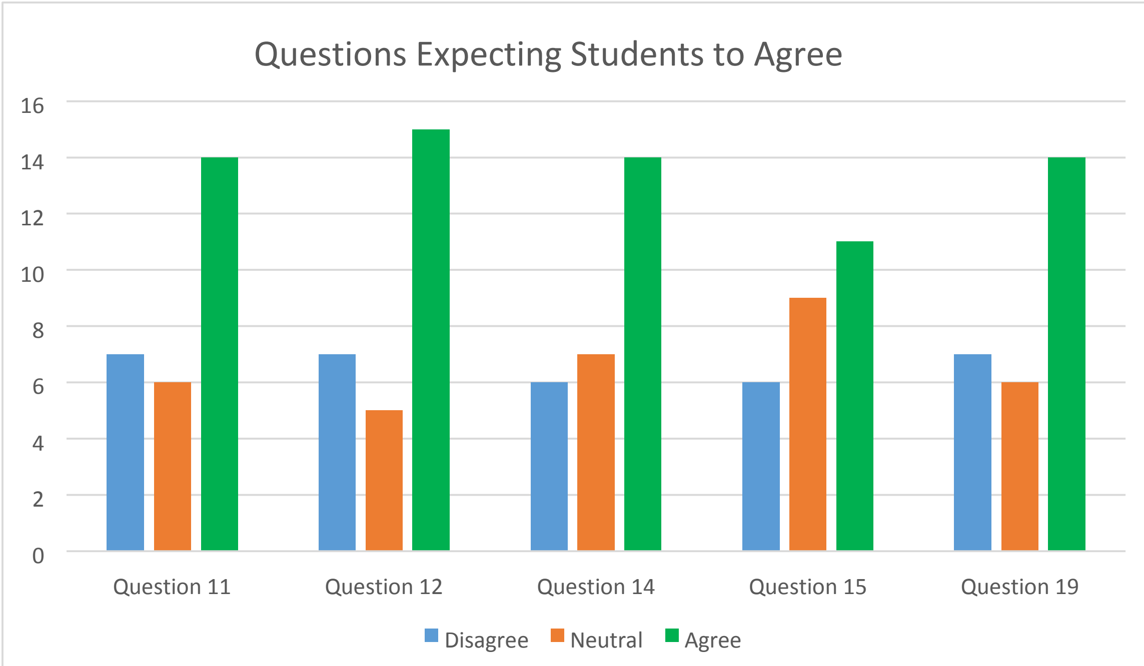

Figure 1: Cumulative Responses on End of Course Survey (Agree Expected)

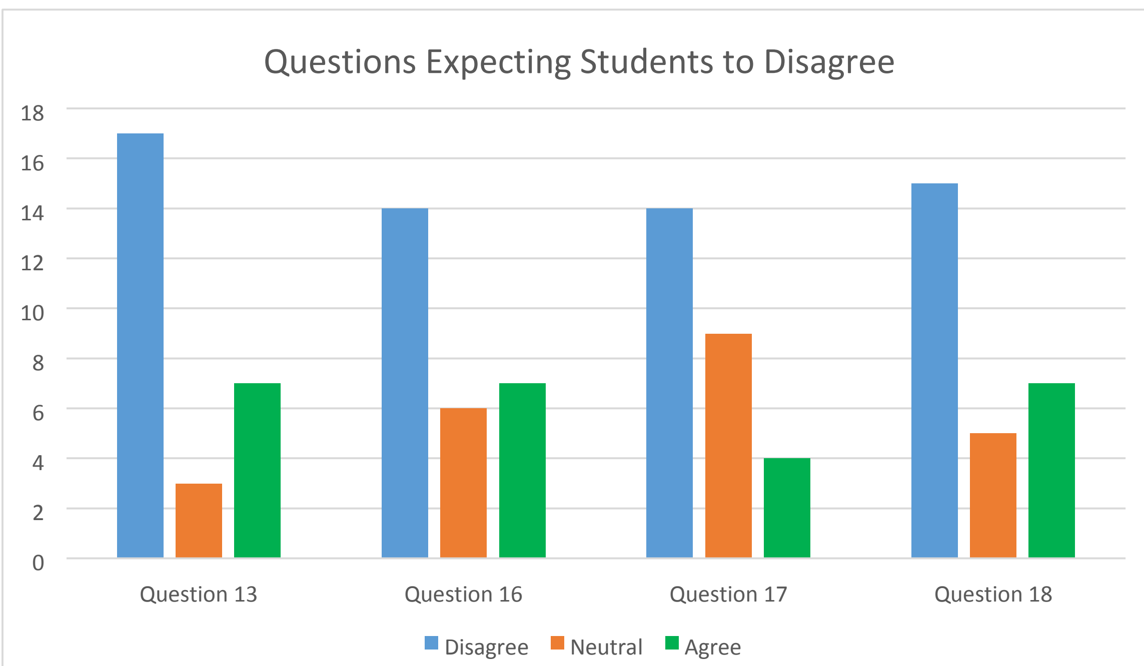

Figure 2: Cumulative Responses on End of Course Survey (Disagree Expected)

In addition to the student surveys, the student curriculum development team was asked to summarize their observations regarding the impact of the CBI materials on the 4th year students. The following selected responses from three of the students reveal some of the development teams' individual attitudes and perceptions about CBI.

> "Challenge based instruction (CBI) is a great way to get students interested in the curriculum from the very beginning. From what I saw, every student was very excited to start building the solar car right away, and started thinking on ideas. But what was very impressive was that as the students progressed through the curriculum, they were able to relate how the curriculum will help them get to their final goal of constructing the solar car… Another reason why I think the CBI method worked well was because students understood the course well enough that they incorporated it into their other classes because they used Blender to model projects from their other classes."

> "Challenge Based Instruction (CBI) is implemented throughout the course and its objective is to help the students by letting them know what information must be learned better in order to succeed at the end of the course when the challenge project is required to be completed. … The objective of the CBI was achieved, as students showed interest in the challenge project, their knowledge and skill significantly improved and therefore were able to explain the basic mechanics of the Stirling engine. The biggest challenge I found while developing the curriculum was to find a way to expose the students to the material, so that they would be interested and could learn more."

> "The main goals of this course material and projects are to get students interested in water science and engineering, provide a good understanding of water and the environment, and allow students to be creative and take initiative in their own learning to be prepare for their future."

Their positive comments mirror the positive results shown in the student end of course survey and positive comments made by the instructor and the development team throughout the summer program. After completion of the summer program, the TexPREP students traveled to take part in a regional science symposium and presented two of their CBI Challenge projects, the Stirling engine and the Solar Car. The students were very excited to share their projects with over 100 other 4th year TexPREP students from around the state.

The undergraduate curriculum development team was encouraged that the CBI curriculum that they developed was beneficial to fourth year students who used the materials that summer and hopeful that students at all TexPREP sites who benefit from the curriculum in years to come. The team members were asked to reflect on their experience and how they were impacted personally. Some of their written responses include the following:

> "Personally, writing the curriculum and implementing the CBI has helped me finding the way to see my classes from other perspective, now I can go through the course syllabus and challenge myself to learn something that I believe will be key for my success at the end of the semester."

> "Personally, with my experience the Challenge Base Instruction (CBI) method of teaching courses is helpful, because it helps to start opening your mind to some new things and look forward in your academic career. For me, since I started to write the curriculum, think about the challenges, and the projects helps me to think more briefly on some ideas for the projects that I wanted to have on the last year of my academic career as part of my senior design project. Some professor at my college are using this new method to teach their classes…"

> "Challenge-base instruction has changed the way I see regular classes since the day that I learn about this particular method of teaching and engaging students, especially in STEM classes which are difficult to relate at first. Sometimes I would like for some professors to adopt the same method of teaching techniques that are used in the TexPREP program so that the students can easily relate to the class material and be engaged in the course. At the same time discovering the challenge-base instruction and developing it in the water science course has helped me grow professionally and personally."

The students expressed that developing a CBI course helped them understand that the content in their college courses is relevant to real world challenges. Several of the students expressed that their experience helped them see their senior capstone design course and even their future engineering careers as a CBI challenge and what they are learning in the engineering curriculum as a support to meeting that challenge. The experience has helped them to see that they are future engineers who want to grow in their knowledge of engineering and not simply students who need to pass their courses in order to obtain an engineering degree.

Conclusions

Undergraduate students can play a significant role in the development of the curriculum for STEM outreach programs as evidenced by the documented successful implementation. The successful development and implementation of a variety of CBI courses has greatly enhanced the TexPREP program. As the newly developed and implemented materials are adopted by other TexPREP programs around the state, the impact of the work will continue to expand. The CBI course material will continue to be revised, however, the core of the course materials will be used with upcoming 4^{th} year students for years come. The positive impact of the curriculum development project has led to a similar effort to introduce an inquiry based pedagogy in the curricula for years one through three. The nine undergraduate students who participated in the curriculum development grew in their understanding of the relevance of their education in light of their future careers. If they become educators they may rely on this useful pedagogy called CBI. As co-authors on this paper they have participated in the challenge of using their engineering knowledge and skills to impact their world and have completed one cycle of CBI by "Going Public" and "Leaving a Legacy".

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