AC 2010-475: DEVELOPMENT AND IMPLEMENTATION OF AN INTRODUCTION TO STEM COURSE FOR DUAL-ENROLLMENT PROGRAMS

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Development and Implementation of an Introduction to STEM Course for Dual-Enrollment Programs

Abstract

A new Introduction to Science, Technology, Engineering, and Mathematics (STEM) course was developed and taught for the first time during the summer in 2009 to dual-enrollment college students at South Texas College (STC). The new *Introduction to STEM* course was developed in collaboration between STEM Faculty members at the University of Texas-Pan American (UTPA) and STC, with the objective of creating, supporting and strengthening STEM pathways for students in the Dual-Enrollment Engineering Academy (DEEA) and other dual-enrollment or similar programs. The course was offered to two groups of students, at two different campuses in the DEEA program at STC. DEEA students take college courses to accomplish an associate degree in Engineering by the end of their senior year of high school. Challenge-based instruction (CBI) was implemented in this new course; challenges, lecture and handout materials, hands-on activities, and assessment tools were developed and implemented in the areas of basic electronics, mechatronics, renewable energy, statics, dynamics, chemistry, reverse engineering, and forward engineering. This paper describes the new course development and implementation, as well as its impact on students and Faculty, including the student assessment results and the interaction of Faculty members from both institutions. The instruction materials and tools developed for the new course could be modified and adapted for implementation in other engineering and science courses at UTPA, STC, and other institutions to increase and improve educational challenges and hands-on activities in the curricula and in recruiting programs and/or activities.

1. Background

This paper presents the developments and results of collaborative work performed between two Hispanic Serving Institutions (HSIs) in order to strengthen and support STEM pathways. The University of Texas-Pan American (UTPA) serves approximately 18,300 students of which about 88% are Hispanics; 57% are females; and 21% of all students are in the college of Science and Engineering. South Texas College (STC) is a community college serving Hidalgo and Starr counties, in the southernmost region of Texas, and about 95% of over 20,000 students at STC are Hispanics, approximately 60% of them are female, and about 75% are first generation students [1]. Qualified high school students are allowed to become college students and enter dual-enrollment programs at STC to take college courses in place of, or in addition to, their normal high school course load [2]. As an exceptional initiative for selected junior and senior high school students, STC has created the Dual-Enrollment Engineering Academy (DEEA) that started in 2006. Students that complete the DEEA program obtain associate degrees in Engineering by the end of their senior year of high school. Students that do not join DEEA in the summer, before their high school junior year, cannot join the program at any other time.

A new *Introduction to STEM* course was implemented in the DEEA program as one of the first courses that the new DEEA students ever take in College. The new course covers fundamental concepts and information about engineering professions, ethics, engineering economics, systems of units, and other topics that are included in the Introduction to Engineering courses at STC and UTPA. In addition, the course also involves CBI with hands-on activities to engage and motivate students to learn and get familiar with practical applications in STEM fields. In this new *Introduction to STEM* course, 53 students participated during the Summer II term in 2009.

2. Supporting STEM Pathways with CBI and Hands-on Activities

In order to support the DEEA program as well as other similar programs at STC, and UTPA, CBI with hands-on activities were developed and implemented to encourage students to integrate and understand multidisciplinary concepts through new instruction approaches. *Introduction to STEM* was implemented as one of the initial steps in this project to use CBI with hands-on activities in early STEM career courses. CBI is a research proven methodology that provides students with an interactive approach in learning and understanding new concepts . The literature indicates that hands-on activities are required to promote STEM interest as a career path. These hands-on activities also allow students to develop abilities and apply concepts and principles to a wide range of problems [3]. Engineers and Scientists need knowledge and skill sets in areas such as hardware interfacing, sensors and actuators, electronics, data acquisition, controls, programming, and modeling and analysis of systems [4, 5]. They require adequate preparation to work on and design systems which are becoming increasingly multidisciplinary. For instance, Mechatronics is an example of a combination of technologies and disciplines in engineering, electronics, intelligent control systems, and computer science, which together can contribute to develop better and smarter products and processes [6-12].

Introduction to STEM included 5 challenges with hands-on activities in basic electronics, mechatronics, and renewable energy topics, covering basic use of electronic equipment and components, like breadboards, power supplies, and resistors, and also activities such as programming and implementing microcontrollers or programmable logic controller (PLCs). Furthermore, this new course also included 5 challenges in chemistry that were selected to expose students to additional science topics, such as general chemistry, electrochemistry, polymers, and preparation of household products. The students learned basic science and their correlation with real life applications, i.e. the interaction of light with matter and how this knowledge can be applied to designing and/or selecting sunblock lotions. Another example of CBI used in this course within chemistry, consisted of studying the synthesis of polymers (rubbers and fibers) and their applications. In addition, challenges were developed and implemented in the area of engineering mechanics: 2 challenges in statics and 2 challenges in dynamics. These challenges included lectures and hands-on activities using lab scale trusses, bridges, carts and collision tracks, load cells, motion, velocity and acceleration sensors and data acquisition systems. Therefore, students were exposed theoretically and experimentally to a great variety of multidisciplinary fundamental concepts in the new *Introduction to STEM* course.

Different CBI studies [13-20] have been performed in recent years and data have been gathered on how challenges should be designed in order to appeal to students, while improving their skills by acquiring and retaining knowledge and understanding the concepts involved in the challenges. CBI is considered a relatively new approach to engage and involve students and instructors in the education process and to continuously keep interest in the subjects, provide feedback, and achieve lasting understanding of concepts and adaptive expertise skills. It is expected that in this project, most students will acquire and retain knowledge by going through the process of searching for solutions to the challenges, which require performing hands-on activities. During this process, students may use and develop their abilities to work in teams and also learn on their own. In general, an improvement in the quality of education is expected by using CBI and hands-on activities.

It has been shown in the book How People Learn (HPL) [18] that learning environments that use knowledge-, assessment-, learner- and community-centered are more effective than traditional methods. Traditional methods are performed with a knowledge centered approach with some summative assessments and no attention to formative assessment. In order to identify weaknesses in the learning process, the instructor and student need to work together to provide feedback through formative assessment, which is a reflective process that intends to promote student attainments. Formative assessment determines the learning level and provides students with prompt feedback. Some activities that allow for formative assessment are problem solving in class, team work in classroom and/or lab activities, which provide the students, and the instructor, with feedback throughout the learning process. Computerized assignments or evaluations with instant feedback are also useful for formative assessment activities. Formative assessment should not count significantly towards the grades of the students, since it is part of the learning/teaching process and provides prompt feedback to make any required adjustments that improve learning. Summative assessment is a form of evaluation, such as an exam, that estimates what the students should have learned over a period of time; it usually counts towards a significant part of the grades of the students.

The new *Introduction to STEM* course was developed with emphasis on CBI with multidisciplinary hands-on activities as a way to inform, motivate, and encourage dual-enrollment students at STC to stay in college and pursue STEM careers. The new course covered the majority of the topics in the Introduction to Engineering courses at UTPA and STC. Furthermore, such topics were complemented with other STEM topics. For instance, students participated in experimental practices and challenges in chemistry, mechatronics, statics, dynamics, renewable energy, reverse and forward engineering, and engineering economics.

3. CBI in the *Introduction to STEM* Course

To successfully implement CBI, several fundamental requirements must be met to ensure that challenges are educationally effective and that students develop adaptive expertise to apply concepts in multiple contexts. It is recommended that the instructor or challenge designer use a backwards design approach in order to develop adequate challenges. The backwards design process consists of determining and prioritizing concepts to be targeted by the challenge, identifying important real world applications of such concepts, and the difficulties students might have learning and understanding them. After that, the objectives and sub-objectives of the challenge have to be established. To implement CBI, numerous questions arise about group size, scheduling of assignments, individualized grading procedures, and how to measure student success in collaborative learning environments. Students should work in teams, Laporte [15] indicated that a group smaller than 3 students might not contain enough diversity while a group of 4 students seems to be diverse enough to provide different working and thinking styles. However, equipment availability, lab space, and class size become important factors to be considered to determine student group size. In *Introduction to STEM*, the group size was set to 3 students and in a few occasions groups were of 2 students. CBI is approached by following the Star Legacy Cycle [20], which presents the structure and process to execute challenges. There is a variety of challenges and some extend beyond the classroom, requiring several assignments, steps, and days of work. CBI and the Star Legacy Cycle [17] take into account that student centered instruction is used to determine student current capabilities, while knowledge centered instruction is a form of traditional lectures focused on teaching to accomplish mastery of a subject. Assessment centered instruction is used to build opportunities for students and teachers to provide feedback throughout the learning/teaching progress; and community centered instruction promotes learning in an appropriate community context [17,18]. Pre-test, post-test, and follow-up evaluations should be used to determine student knowledge and understanding of the challenge concepts before and after the challenge, which are useful to estimate student learning and adaptive expertise. Affect surveys are convenient tools to determine student opinions about the challenges and learning/teaching process and methods being implemented.

3.1 Challenge-Based Instruction and Star Legacy Cycle Steps

The main steps in the Star Legacy Cycle [17] used in the process to implement and solve a challenge are the following:

- **Challenge:** A challenge is designed based on a realistic problem, neither too trivial nor impossible for the students to solve. The challenge has to engage students in the learning process in order to search, inquiry, test, and go public to determine and present an adequate solution. A pre-test is implemented to determine the initial level of knowledge the students have about the targeted concepts.
- **Generate Ideas:** Organized in teams, students are asked to generate ideas about the challenge and to communicate possible limitations or problems that need to be considered in order to solve the challenge. The pre-test results and the generated ideas are used by the instructor to determine misconceptions and concepts that might require greater effort for students to understand.

- **Multiple Perspectives:** Different points of view are used in the Legacy Cycle [17] to engage students to understand the importance of solving the challenge. The process starts with broad ideas from different sources and then narrowing them down to what the students need to accomplish and learn.
- **Research and Revise:** Following multiple perspectives, research and revise is the following step in which students do most of their formative learning through lectures, handouts, hands-on activities, and other sources, such as textbooks and publications, and through asking questions to the instructor or other experts. Revising consists of studying, researching, and completing class activities and/or homework assignments related to the challenge to ensure that students are learning and progressing.
- **Test Your Mettle:** Students test their mettle through quizzes, post-test, lab reports, exams, and/or demonstrations of the hands-on activity results, all of which could be summative assessment tools used to compute student grades. Students need to look ahead and reflect back and provide solutions to the challenge.
- **Go Public:** Finally, students go public with their findings by presenting and defending their solutions to the challenge. These presentations also allow each student to see other solutions to the same problem to find out that there might be multiple ways to solve the challenges [16].

3.2 Challenges in *Introduction to STEM*

The challenges developed for the *Introduction to STEM* course are presented in Figure 1; the ones with the "*" mark were not implemented during the summer in 2009 due to time limitations. However, they were prepared and could be used in the future. All these challenges have hands-on activities as part of the *research and revise*, *test you mettle*, and *go public* parts of the Star Legacy Cycle.

- Basic Electronics and Mechatronics:
  - Video Game System Problem
  - Forcing Hot Air Out of House Attics
  - Home Alarm System
  - Automation with PLC Programming*
  - Renewable Energy Challenge
- Engineering Mechanics:
  - Statics: trusses and bridges
  - Dynamics: linear motion and collisions
- Chemistry
  - How can UV sensitive beads be used to test sunscreens?
  - How can a battery be made from coins?
  - Synthesis of Polymers
  - Preparation of Soap
  - Cold and Hot Packs
- Engineering Design:
  - Reverse Engineering*
  - Forward Engineering

Figure 1. Challenges developed for the *Introduction to STEM* course

Other activities were developed for the *Introduction to STEM* course for students to work in the classroom and/or computer room in topics such as systems of units, data presentation and graphing, engineering economics, ethics, and STEM education and professions.

A description of one of these challenges is presented next to demonstrate the challenge design process, the developed instructive materials, assessment tools, and the results that were obtained in the new Introduction to STEM course during the first implementation of the challenges. Similar instruction materials and assessment tools were developed for each challenge presented in Figure 1.

4. Example of a Challenge in Electronics: Forcing Hot Air Out of House Attics

This challenge was implemented for the first time in the *Introduction to STEM* course at STC during the summer II term, in 2009, and it has been improved during the Fall 2009 semester when it was also implemented in a similar way in the Introduction to Mechatronics course in the Mechanical Engineering Department at UTPA. This challenge, and most of the others in Figure 1, was performed during a 4-hour period. At first, a 10-minute pre-test was given followed by handing out the challenge to students, who proceeded to generate ideas during a 15-minutes period. After that, the instructor presented a lecture with some examples and information about the challenge concepts and also explained the goals and procedure of the hands-on activity for about 45 minutes,. Students received a handout with additional background information and the lab procedure to create the desired electronic circuit. The class went to the lab for about 2 hours, where students started reviewing the information in the handout, identified the equipment and components required for the hands-on activity, and performed the experiments. Finally, during the last 30 minutes, the students went back to the classroom to prepare the conclusions and presented their results and a solution to the challenge.

4.1 Backwards Design

This challenge was developed to get students involved in electronics in *Introduction to STEM*; but, it could be modified to be used in other instrumentation, electronics, or mechatronics courses. In general, to develop challenges for specific topics in a course, instructors need to take a backwards design approach starting by identifying all the target concepts that students are going to learn and understand by the end of the challenge. For example, Figure 2 presents the dispersed concepts students are supposed to understand and integrate by the end of this challenge.

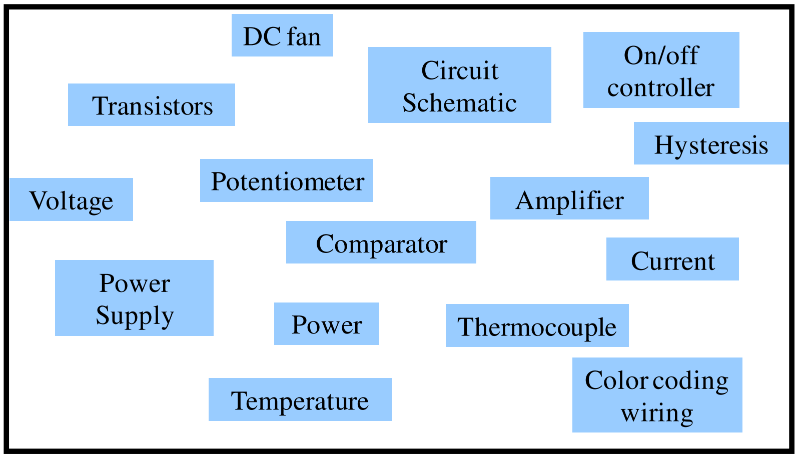

Figure 2. Target concepts and components for the challenge.

The instructor then specifies the objectives, sub-objectives, difficulties, and real-world applications and contexts associated with the challenge, and the ones for this specific challenge are presented next:

- Primary Objectives. By the end of this challenge, students will be able to:
  - Understand voltage and temperature relationship for a thermocouple.
  - Build an on-off control system using a thermocouple signal to set the state of the controller's output.
  - Learn the basic usage of amplifiers, comparators, and transistors.
  - Build an on-off controller with hysteresis using an integrated circuit comparator.
  - Control the on/off condition of a 12 Vdc fan based on temperature measurement.
- Sub-Objectives. The objectives will require that students be able to:
  - Use circuit schematics, breadboard, and power supplies.
  - Measure resistance, voltage, and current using a digital multimeter (DMM).
  - Understand and use a potentiometer.
  - Understand and use amplifiers.
  - Understand and use a transistor.
- Difficulties. Students have difficulty with:
  - Correctly following circuit schematics using breadboards and power supplies to implement electronic circuits.
  - Implementing circuits on a breadboard using transistors, potentiometers, amplifiers, and comparators.
  - Implementing an on/off controller with hysteresis and validating the theoretical relationships of voltages and currents in the circuit.
  - Correctly analyzing power, current, and voltage requirements by a DC load, such as a 12 Vdc fan.
- Real-World Contexts
  - Sensors, amplifiers, and controllers are present in almost any device that has been developed with modern electronic technology.
  - There are many common applications that use on/off controllers based on physical parameter readings such as temperature, pressure, speed, and light intensity, among others.

    - Operational amplifiers are used to make extremely low voltages, like the ones from thermocouples, more manageable by comparators, transistors, and other electronic components and data acquisition systems.
    - Learning the mentioned concepts and acquiring hands-on experience in basic electronics are intended as the first steps to encourage students to pursue a career in a STEM field.

4.2 Model of Knowledge

The instructor or challenge designer has to categorize and prioritize the target concepts of the challenge in a similar way to the example presented next for the Electronics challenge:

- Concept Map: following is a categorized list of target concepts in this challenge.
    - Electronic components
        - Understand and use potentiometer, transistor, amplifier, thermocouple, DC fans, and power supplies
        - Understand units of voltage, temperature, current, power, and energy
        - Understand symbols and schematic diagrams for electronic circuits
    - Electronic Instruments
        - Understand and use breadboards and DMMs
        - Understand and measure of resistance, voltage, current, and power
    - On/off controller
        - Understand and use comparator integrated circuits
        - Understand setpoint or reference voltage
        - Understand hysteresis of an on/off controller
- Content Priorities: next is a prioritized list of understanding concepts targeted by this challenge.
    - Enduring Understanding
        - Understand a circuit schematic
        - Using a breadboard and color coding the wirings
        - Understand and use a thermocouple
        - Understand and build an on/off controller
    - Important to Do and Know
        - Understand and use amplifiers
        - Understand and use potentiometers
        - Understand hysteresis
    - Worth Being Familiar with
        - Understand and use transistors
        - Understand and use comparators
        - Understand and use amplifiers
        - Computation of power and energy consumption by DC loads

4.3 Assessment of Learning

A plan has to be created to develop the assessment tools required to collect information that allows generating conclusions about student understanding of the targeted concepts. Next is the assessment plan for this example challenge:

- Formative Assessment: it consists of practice activities, which should not count in a significant way as grades; however, it needs to provide feedback to the students and the professor in order to address any learning problems or difficulties.
  - Pre-test.
  - Classroom activities:
    - Study working principle and connections of thermocouples and operational amplifiers.
    - Study potentiometers and comparators.
    - Study the circuit schematics of an on/off controller with hysteresis and explain their working principle.
  - Lab Work
    - Implement a circuit schematic using a breadboard.
    - Amplify the voltage from a thermocouple.
    - Understand a comparator and make the connections to use it correctly.
    - Implement an on/off controller and test it.
    - Explain the results of the hands-on activities and the reasons why the system might not function properly.
- Summative Assessment: examples of this type of assessment are solutions to the challenges, post-tests, midterm exams, or final exams, which are usually part of the student grade for the challenge.
  - Prepare a report with answers to handout questions and indicate challenge conclusions.
  - Present or discuss solutions to the challenge.
  - Post-test.

4.4 The Challenge

It is recommended to design challenges that engage students in the learning process by assigning them responsibilities and tasks related to real-world situations that include some expectations of their work efforts and consequences of their achievements to be obtained through understanding and solving the challenge. Figure 3 presents the challenge used in this example.

Challenge: Forcing Hot Air Out of House Attics
You are a Consultant Engineer working for a famous construction company and you are the leader in a project to design a new system to get hot air out of the attics in new houses especially in summer time. This will be a new system for houses that are for sale to make them more energy efficient; therefore, attracting more buyers and making the houses easier to sell.

Figure 3. Challenge about Electronics

Notice that even though the students are going to be presented with multiple perspectives to promote student engagement and to obtain broad ideas about on/off controllers, thermocouples, cooling systems, and other concepts of interest in the challenge, the instructor guides the students to focus their attention to the specific activities that are expected to be completed in the classroom, at home, and in the lab.

4.5 Generate Ideas

Students were requested to brainstorm and write down ideas about the challenge, the importance of finding a solution, difficulties, and limitations. Some of the students' generated ideas are included next:

- Create a ventilation system to allow air to flow.
- Manipulate the A/C to cool the attic.
- Vacuum the air out.
- We need to find ways and tools to take hot air out.
- Small opening in the shingles to let cooler air in to force hot air out.
- Add fans that let fresh air in and hot air out.
- Install solar powered fans. Multiple vents in the walls.
- Sprinkling system on roof to keep it cool.

Notice that some of these generated ideas are incomplete sentences. It is recommended to request that students do the generation of ideas as homework after they get the challenge statement. Therefore, request the students to write down complete sentences about the challenge, possible solutions, assumptions, and the difficulties to solve the challenge. They should also prepare a list of questions to completely understand the challenge.

4.6 Multiple Perspectives

The instructor, other experts, or other sources present students with information about common applications of temperature sensors and on/off controller applications in residential air conditioning systems and cooling systems for computer cases, among others. Multiple perspectives are needed in order to develop a discussion to determine current or potential applications of the challenge concepts, and to identify their importance, advantages, and limitations. In this challenge example, information from different sources was presented in lectures about on/off controllers. The lecture could take many different directions indicating that students might already be engaged in the subject. The instructor has to lead the discussion in the desired direction, so that students focus and learn the concepts targeted by the challenge before they go on their own direction to discover additional complementary or distracting information. The internet is a common source of technical and non-technical information useful to provide students with multiples perspectives about challenge concepts.

4.7 Research and Revise

In this part of the challenge, the instructor proceeds to present traditional lectures to explain concepts, work with examples, and implement classroom activities. In this challenge, the instructor presents a lecture about thermocouples, operational amplifiers, potentiometers, comparators, and on/off controllers with hysteresis. In addition, a handout with additional information about the particular components to be used in the hands-on activity for the challenge was provided to the students. An example section of this handout is in Figure 4.

Students need to dedicate time in this part of the challenge to study the handout to determine the steps, components, and materials required during the hands-on activity. Students also need to study the lectures, the background information presented in the handout, and search for additional information in the library or internet, to understand the challenge concepts and the purpose of the hands-on activity. This might be a difficult step to achieve in a single day challenge during the class period; therefore, students might have to do homework before and after the class time to satisfactorily achieve a solution to the challenge and to accomplish a good understanding of the challenge concepts.

AD594 J-Type Thermocouple Amplifier
A special J-type thermocouple amplifier called AD594 is used to convert the small voltage from a J-type thermocouple into another voltage more convenient to read with a multimeter. Notice in Figure 3 that pin 8 has the voltage output indicating 10 mV/ºC. Therefore, by measuring the voltage in milivolts between pin 8 and ground, we can get the temperature of the thermocouple junction with the 10 mV/ºC relationship.

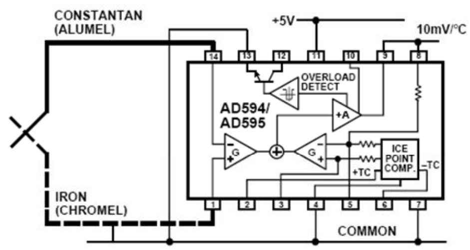

Figure 3. AD594 and thermocouple type J (source: AD594 datasheet)

Operational Amplifiers (Op-Amps)
An operational amplifier multiplies the difference between two input voltages by a gain. The amount of amplification or attenuation is known as the gain of the amplifier. In this experiment, an op-amp named INA106 with a fixed gain of 10 will amplify the output voltage from the AD594 J-type thermocouple amplifier. The schematic symbol for an operational amplifier is shown in figure 4.

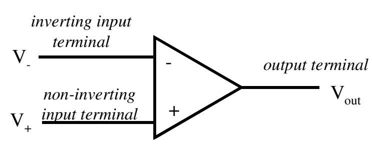

Figure 4. Operational Amplifier

Figure 4. Section of handout for hands-on activity

4.8 Test Your Mettle

In this part of the challenge, students are required to demonstrate that they understand the challenge concepts. Following is a list of possible activities that can be performed to test students' mettle:

- Students perform experiments (work in the lab to learn through hands-on activities). Instructors ask questions to students, who explain their experimental results.
- Post-test.

- Students report the answers to the questions in the handout. Another example of a handout section where students need to indicate the results of measurements and validate theoretical results is presented in Figure 5.

Thermocouple with Thermocouple Amplifier and Operational Amplifier

(a) Set up the circuit as shown in figure 11. Use a J-type thermocouple and measure the output voltage when the thermocouple is at room temperature. Now, look at the output voltage when the thermocouple is heated between your fingertips.

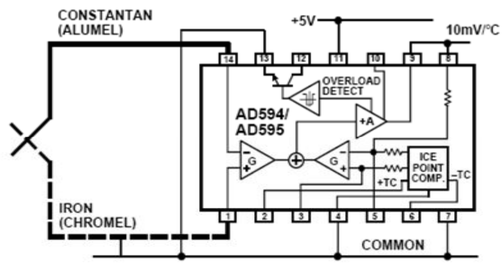

Figure 10. AD594 and J-type thermocouple.

The common voltage is the same as ground (0V), the constantan is the red wire and the iron is the white wire of the thermocouple. V_{out} is measured between pin 8 and ground. Every 10 mV of the output voltage equals about 1°C.

(b) Determine the room temperature by converting the output voltage from the AD594 to temperature using the relationship of 10 mV/°C. Use the DMM to measure the output voltage.

$V_{out\_room\_temp}$ =___________ ; $V_{out\_fingers\_temp}$ =___________

T_{room} =________________ ; $T_{fingers}$ = ______________

Figure 5. Handout section to test students' mettle, collect data, and validate theory.

Notice that the handout in Figure 5 has sections for students to collect experimental information that is used for subsequent analysis of results and validation of theoretical computations.

4.9 Go Public

In is an important step that students go public to complete the Star Legacy Cycle approach to solve the challenges. Going public imposes a positive degree of accountability for students to work and dedicate satisfactory effort in the classroom and lab to achieve results, demonstrations, and presentations that they can proudly share with others. Examples of going public activities in this challenge are:

- Students demonstrate the results of their hands-on activities to the instructor and other students. In the case of this challenge, students show and explain how their electronic circuits work.

- Students report the results and conclusions, including possible solutions to the challenge.
- Students show pictures, videos, and/or presentations.

4.10 Challenge Conclusions: Look Ahead and Reflect Back

In this part, students make recommendations and conclusions. Students were asked to explain what they learned in the challenge, reasons why the on/off controller with hysteresis is important and the reasons why it might not work properly. Students were also asked to explain a solution to the challenge. Next are examples of the conclusions reached by students during this challenge.

- It is important because it turns on only when it is needed. For example, the fan turns on only when it is hot.
- It is a helpful way to maintain temperature and yet still not wasteful on electricity.
- The on-off temperature controller helps save energy and maintains a certain temperature.
- I learned how to set up an on-off controller.
- Saves electricity. Works when necessary. Relatively compact.
- Install sensors that detect high temperature and activate fans when temperature is too hot.
- Possible lower air conditioning use. Amplifiers make voltage higher. I learned how to make a hysteresis circuit. I learned how to read an electric schematic.
- I learned how to put together a circuit.

These student conclusions show that they got a good understanding of an on/off controller with hysteresis and that they correctly explain possible causes of circuits malfunctioning, according to what they experienced during the hands-on activity and what they learned in all steps of the Legacy Cycle approach used to solve the challenge.

5. Assessment of Learning

The true/false questions in Figure 6a were used in the pre- and post-test in the example challenge presented in section 4 and that were used in order to estimate student understanding of the targeted concepts before and after the challenge. Figure 6b presents the multiple choice questions in that were also used in the pre- and post-test in the basic Electronics challenge in order to estimate student understanding of the targeted concepts before and after the challenge.

As can be noticed in Figure 7, students did a good job acquiring and retaining knowledge related to the temperature-based on/off controller with hysteresis studied using a challenge-based instruction approach. The overall effect of the challenge was to increase student knowledge in basic electronics concepts. The average correct answers for the pre-test were 63.0% and for the post-test were 85.4%; meaning that there was an improvement of 22.4% correct answers.

Pre-Test/Post-Test

Part 1. True/False Questions

1. T ☐ ; F ☐ ; Every bipolar junction transistor (BJT) has base, emitter, and collector.
2. T ☐ ; F ☐ ; An on-off controller can be made with a comparator to activate or deactivate an electrical device.
3. T ☐ ; F ☐ ; Voltages from a thermocouple are usually large.
4. T ☐ ; F ☐ ; Small voltages can be increased with operational amplifiers.
5. T ☐ ; F ☐ ; Resistors are used in circuits to limit electrical currents.
6. T ☐ ; F ☐ ; An integrated circuit comparator is used to compare electrical resistors.
7. T ☐ ; F ☐ ; Hysteresis is useful to avoid fast on-off cycles of electrical devices.
8. T ☐ ; F ☐ ; A transistor acts as a switch when it is saturated.
9. T ☐ ; F ☐ ; A thermocouple is used for heating objects.
10. T ☐ ; F ☐ ; A J-type thermocouple amplifier generates voltage proportional to temperature.

Figure 6a. True or false part of the pre- and post-test.

Part 2. Multiple Choice

11. Forcing hot air out of a house attic in the summer helps to:
    a) increase the electric bill.
    b) keep the ceiling of the house hotter.
    c) increase the temperature in the hot water tank.
    d) increase air conditioning usage.
    e) keep the air conditioning off for longer times.
12. A bipolar junction transistor (BJT) can be used as a:
    a) comparator.
    b) thermocouple.
    c) amplifier.
    d) switching device.
    e) temperature sensor.
13. An integrated circuit comparator can be used to:
    a) create an ON-OFF controller with hysteresis.
    b) create a velocity controller for a fan.
    c) amplify a voltage.
    d) measure electrical resistance.
    e) determine the velocity of a fan.
14. A thermocouple consists of
    a) an amplifier.
    b) a junction of two wires made from different metals.
    c) a transistor and a resistor.
    d) an attic fan.
    e) an air conditioning system.
15. Hysteresis is
    a) a computer virus.
    b) a type of fan.
    c) a range difference in an input value used to turn something on or off.
    d) a transistor.
    e) a temperature amplifier.

Figure 6b. Multiple choice part of pre- and post-test.

Figure 7 presents the results of the pre- and post-test in this example challenge in which 53 students participated in the DEEA program at STC during summer II term, in 2009.

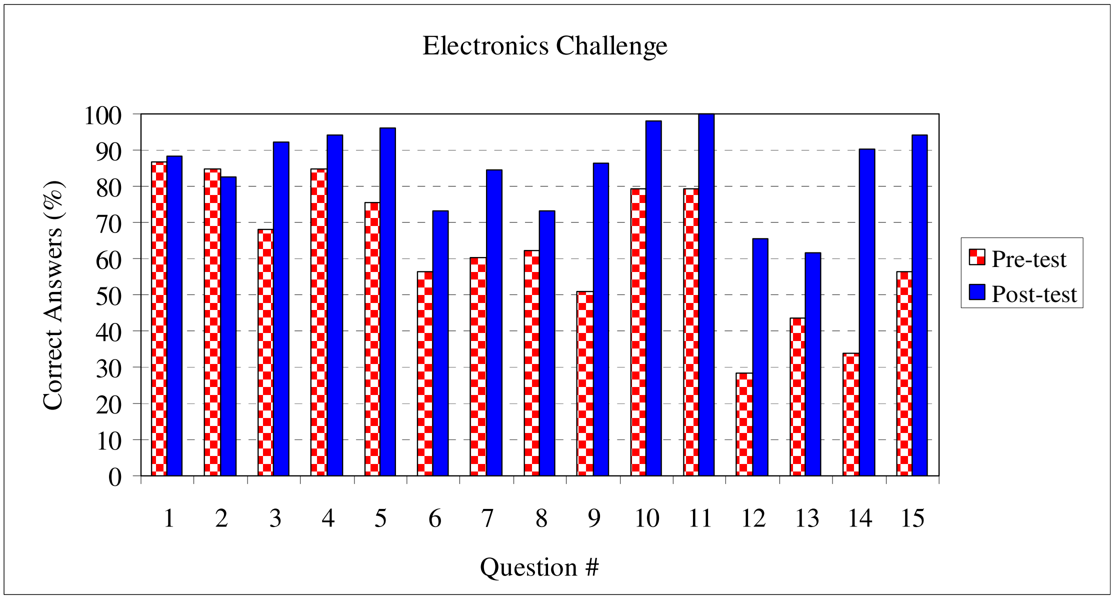

Figure 7. Results of pre- and post-test.

A drawback of using true or false questions is the high probability of selecting the right answer just by guessing. This condition, combined with the fact that only 3 of the 10 true/false questions has false as an answer, might have un-expected conflicting results especially on the pre-test. For instance, the instructor expected and was aware that students were not familiar with the concepts in questions 1 and 2, however, the pre-test results seem to show the opposite. Therefore, multiple choice questions are recommended as a better option for future challenge assessments. Nevertheless, it is also important to select the answers of the multiple choice questions in such a way that there is not an obvious correct answer as one of the choices.

Questions 3, 4, 5, 6, 9, and 10 are related to thermocouples, amplifiers, resistors, and comparators and the average correct responses for these questions in the pre-test was 63.8% and on the post-test was 88.4%, which means an improvement of 24.6%. Even though questions 1, 2, 4, and 8 obtained an average 84.6% correct answers on the post-test, they got little improvement with respect to the pre-test results for the same questions. Being 1-10 true/false questions, 50% would be expected to answer correctly if just guessing.

Finally, multiple choice questions 11-15 were about transistors, on-off controllers, thermocouple, and hysteresis and while the average correct responses for these questions in the pre-test was 48.3%, it was 82.3% on the post-test, which means an improvement of 34.0%.

A point of future investigations might be to compare the effects of challenge-based instruction to that of traditional lab-based activities, and in particular to compare not only knowledge and understanding but also students' adaptive expertise skills in different contexts.

6. Affect Survey

The affect survey presented in Figure 8 was performed to determine students' opinion about the challenges implemented in the area of basic Electronics and Mechatronics in the new Introduction to STEM course at the DEEA program in STC.

Affect Survey

Please carefully read the questions and provide us with **an assessment of the Electronics and Mechatronics Challenges and Activities** in this course: basic Electronics, Electronics, Mechatronics, and Renewable Energy.
Use the following scale and circle a number for each corresponding question:

1. Strongly disagree
2. Disagree
3. Neither agree or disagree
4. Agree
5. Strongly Agree

I was able to recall previous knowledge and apply it to my challenge
1 2 3 4 5

I enjoyed the Challenge Based Instruction and the overall experience of the legacy cycle
1 2 3 4 5

Working together with classmates helped my overall learning experience
1 2 3 4 5

These challenges did nothing to enhance my learning experience
1 2 3 4 5

These challenges helped me apply my critical thinking skills in order to solve the problems.
1 2 3 4 5

Figure 8. Affect survey for basic electronics and Mechatronics challenges.

The results of this affect survey for the four challenges that were implemented in the area of Electronics and Mechatronics are presented in Figure 9. Note that a specific survey could be eliminated form survey data if the response to question 4 contradicts other responses, because that means that the student did not read the questions.

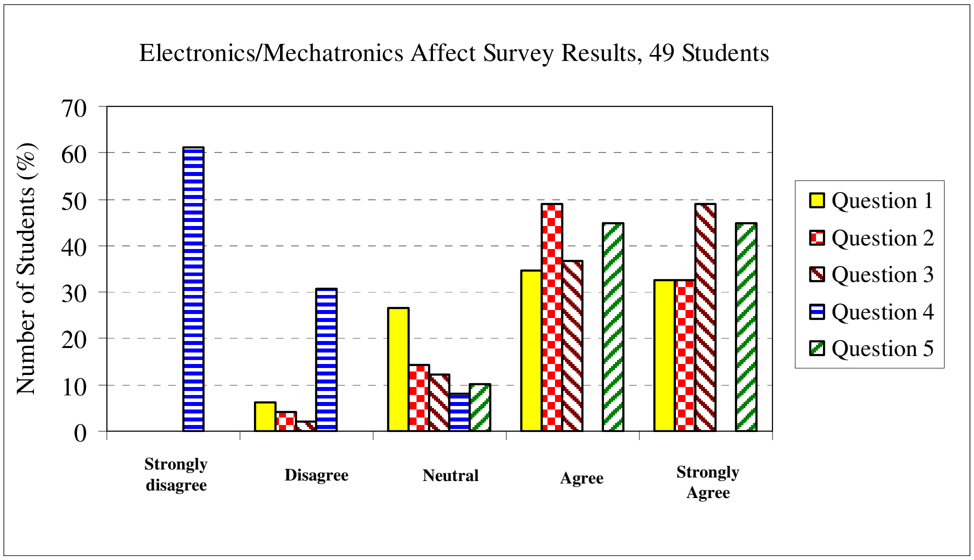

Figure 9. Affect survey results for basic electronics and Mechatronics challenges.

Except in question #1 of the affect survey, the majority (90% or more) of the students indicated to "agree" or "strongly agree" in a positive way towards the experience they had in the Electronic/Mechatronics challenges as part of the Introduction to STEM course. Disagree or neutral as an answer to question #1 is a reasonable response because it is expected that some students do not recall any previous information related to the challenges.

7. Conclusions

A new *Introduction to STEM* course was developed with hands-on CBI modules. Several challenges were developed and most of them were implemented during the summer 2009 in the DEEA program in two campuses at STC. An example challenge in the area of electronics was presented and discussed in detail in this paper. Examples of instruction materials and assessment tools were also presented. Analyses of the assessment results indicate a high level of student achievement and satisfaction with the new *Introduction to STEM* course as well as with the challenges, hands-on activities, and teamwork. Students that took the *Introduction to STEM* course acquired a basic understanding of multidisciplinary STEM concepts, and as a result, comprehension of related new material might become more meaningful, interesting, and practical because of the experience acquired in this early career course. This work has been developed as part of a College Cost Reduction Access Act (CCRAA) grant from the US Department of Education to UTPA in collaboration with STC. The novelty of the initiative presented in this paper is developing and implementing CBI with hands-on activities in a new Introduction to STEM course.

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