Using the Experiential Learning Model to Introduce K-12 Teachers to Control Systems Engineering

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Abstract— **This innovative practice full paper presents a practical case study that demonstrates how to make an engineering-focused professional development program for K-12 teachers effective. It describes the design and implementation of a summer program that engages K-12 teachers in control systems engineering research with the aim of translating the gained experience into relevant engineering-based learning activities for the teachers' K-12 classrooms. Using the experiential learning model, teachers were systematically introduced to the area of control systems engineering while qualitatively gaining an understanding of the mathematics behind the analysis and design aspects of the control system. Teachers participated in building, simulating, and real-time testing of a feedback controller for the regulation of the angular position of a direct current (DC) motor. Connections between the research experience and relevant K-12 learning activities were identified, leading to the development of lesson plans that were implemented in the teachers' classrooms during the following academic year.**

Keywords— Professional development for teachers; Control systems engineering; Engineering content in science and mathematics; Experiential learning model.

I. INTRODUCTION

There have been several national and international initiatives that aim at introducing engineering in K-12 classrooms [1]. Education research has shown that there is a strong correlation between the introduction of engineering-based activities in pre-college classes and students' achievements in science and math [2]. Additional reported benefits of early exposure to engineering include: increased student motivation to learn science and math [3, 4], and increased interest of students for the study of engineering in college and the pursuit of a career in a STEM field [5]. Examples of initiatives to increase the number of students entering the STEM pipeline include the establishment of STEM high schools [6], and science and math summer camps [1].

Due to the strong link between engineering, math and science, several initiatives have been taken to introduce engineering content in K-12 math and science curriculum. The motivation behind these initiatives is twofold: (i) make a connection between math and science concepts to real-world applications to engage students and motivate them to learn math and science concepts, and (ii) promote pathways for students to be part of post-secondary STEM degree programs.

Data published in the 2012 National Survey of Science and Mathematics Education report shows that the United States faces serious challenges when it comes to the training and preparation of teachers [7]. For instance, only one-third of the surveyed middle school math teachers have a degree in mathematics, and a large number of teachers do not feel well prepared to plan instructions that meet the needs of students at varying levels of science and math understanding. Teachers who are not well prepared usually do not feel comfortable teaching challenging science or math concepts. Consequently, it is not uncommon to find teachers, who are not comfortable teaching challenging content, to either teach the content superficially or not teach it at all [8]. Because teachers are the single most important factor affecting student achievement [9], the lack of teacher's confidence in teaching concepts may have negative impact on student learning and attitude towards the subject [10].

To address this concern, several models of professional development programs have been designed to increase math and science teachers' content knowledge. One model of teacher professional development program provides teachers the opportunity to experience engineering first-hand and learn how to relate math and science concepts they teach in the classroom to real-world engineering applications [11-15]. These professional development programs are designed to increase the engineering content knowledge of math and science teachers, thereby having a direct impact on student achievement in math and science and helping to promote positive students' attitudes to engineering [11-15]. However, these studies do not present the best practices for engaging teachers in engineering within the context of professional development programs that are often run over a short period of time. Because most teachers do not have prior experience or background in engineering, an important contribution of this paper is to present a practical case study that demonstrates how to make an engineering-oriented professional development program for K-12 teachers effective. The goal of our professional development program is to provide teachers

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a meaningful and authentic experience working on an engineering project, and not to resort to mere observations or shadowing engineers working in the lab.

The paper describes the design and implementation of a summer program that engages K-12 teachers in control systems engineering research with the aim of translating the gained experience into relevant engineering-based learning activities for the teachers' K-12 classrooms. Because of the authentic engineering project that teachers worked on, the professional development program was designed to offer adequate support to engage teachers in the various aspects of the project following an experiential learning approach. The paper explains how this approach was used to systematically introduce teachers to the area of control systems engineering while qualitatively gaining an understanding of the mathematics behind the analysis and design aspects of the control system design. Teachers participated in building, simulating, and real-time testing of a feedback controller for the regulation of the angular position of a direct current (DC) motor. The paper also provides an overview of the K-12 engineering-inspired learning activities developed by the teachers and the results of the classroom observations.

II. Overview of the Professional Development Program

The professional development program at the University of Texas Rio Grande Valley engages K-12 math and science teachers in engineering research experiences and other professional development activities during a six-week summer program. The main objectives of the program are to: (1) increase teachers' understanding of engineering through an active participation in authentic engineering research projects, (2) acquire new knowledge of real-world applications of math and science concepts, and (3) learn new skills for developing engineering-inspired hands-on learning activities for K-12 classrooms.

The program ran for the period of three years and a total of thirty six teachers were selected to participate in our summer professional development program. A total of thirteen engineering projects in the field of electrical engineering were offered and teachers worked in teams of two or three on each project under the mentorship of an engineering faculty. The teacher teams are formed based on the teacher research interests and the degree of relevance of the research activities to the subjects they teach.

This paper presents the practical case study of the engineering research and curriculum activities of a team of two teachers who worked on the control systems engineering project. One participant is a tenth grade level math teacher in High School and the second participant is a fourth grade level math teacher who also runs an engineering enrichment program at an elementary school. Our effort to form vertical teams is motivated by existing studies that have shown that vertical teaming in professional development of teachers has the potential of improving the alignment of the curriculum and providing continuity in math/science content for students [16, 17]. In our program, we strive to ensure that each member of a multi-grade level teacher team is equally engaged in a research project by using the following strategies: (1) provide training to all teachers in laboratory methods including hands-on engineering related workshops, (2) provide opportunities for vertical teams to discuss with the program management team the relevance of the research project to the math and science concepts taught across grade levels, and (3) provide the option for teachers on the same team to consider the development of student learning activities based on similar engineering topic but with different levels of challenge tailored to multiple grade levels.

Fig. 1. The Professional Development (PD) Process: Activities for Engaging Teachers to Experience Engineering Research and to Develop K-12 Hands-on Learning Activities

The process for the summer professional development program is illustrated in Fig. 1. The program included several workshops and seminars to provide the necessary tools and knowledge for teachers to conduct the assigned research projects and to help guide them to translate their research experiences into K-12 classroom activities. The workshops included:

- Laboratory safety workshop: the workshop was tailored for the teachers and was offered by a staff member from the Unviersity Environmental, Health, Safety and Risk Management Department.
- Library database workshop: this hands-on workshop was offered by a librarian and focused on what the teachers needed to know to search for technical articles and resources that are related to their engineering project. Teachers were also provided with reading materials on

topics such as DC motors and rapid control prototyping technology.

- Engineering design process workshop: this workshop introduced teachers to the different phases of an engineering design cycle.
- Technical writing workshop: offering this workshop was important because teachers are required to write weekly technical progress reports, a final report, and a poster of their research projects.
- Curriculum workshops: An important component of the summer program is to develop hands-learning activities that are inspired by the engineering research projects. Discussions of engineering connections to math and science concepts, and review of Texas STEM and International Technology and Engineering Education Association (ITEEA) standards were conducted.
- Weekly group discussions and end-of-the summer poster presentation: a weekly meeting with the program management team was held to promote discussions between all teacher teams. The purpose of the weekly research meeting is three-fold: (i) teachers learn about research activities conducted by other teams, (ii) project management team monitors progress made by the teachers, and (iii) questions are answered and concerns by teachers are addressed by the program management team. At the end of the summer program, teachers participated in a poster symposium where they presented their research projects and newly developed curricula.
- Engineering career seminar: this seminar was conducted by an engineering career placement advisor. Its purpose is to provide teachers a better understanding of what engineers do. It covered engineering education preparation, different engineering job classifications, and overview of U.S. companies that hire engineering graduates.

III. THE ENGINEERING HANDS-ON EXPERIENCE

A. The Control Systems Engineering Problem

The team of teachers were hosted in the Robotics and Control System Lab where the engineering faculty mentor and his students conduct research on robust control design and real-time testing of control systems. Control systems are omnipresent in our daily lives. Examples of control systems that teachers and their students are likely to be familiar with include simple applications such as the thermostat and complex applications such as cruise control systems and anti-lock braking systems in vehicles. The objective of the research project is to design and implement a control system to regulate the angular position of a DC motor. A block diagram of the control system is shown in Fig. 2. Real-time (RT) testing of the control system on an actual DC motor have to be conducted using the Rapid Control Prototyping (RCP) technology that involves the use of dSPACE DS1104 Rapid Control Prototyping hardware and software, MATLAB/SIMULINK software, and an H-Bridge electronic circuit. The teacher participants had no prior experience or background in control system engineering. Consequently, teachers felt that the project seemed ambitious and complex to be completed during the six week summer program.

Our goal was for teacher team to have a meaningful and authentic experience working on an engineering project and not to resort to mere observations or shadowing engineers working in the lab. This required that the professional development program be designed to offer adequate support for teachers to engage in the various aspects of the project following an experiential learning approach. For this particular project and team, a MATLAB/SIMULINK workshop was conducted. The hands-on workshop introduced teachers to the engineering software MATLAB/SIMULINK. Examples of SIMULINK models were provided for teachers to study and simulate.

Before starting working on the actual project, teachers learned that a DC motor converts electric energy into mechanical energy. They also learned the various applications of DC motors. Teachers also needed to identify known applications of automatic control and learn about the omnipresence of control systems in society. Examples such as, thermostats, automobile cruise control system, automobile anti-lock braking system were discussed. Teachers needed to appreciate the control systems project and how it relates to real-world applications so that they can easily communicate their experience to their students.

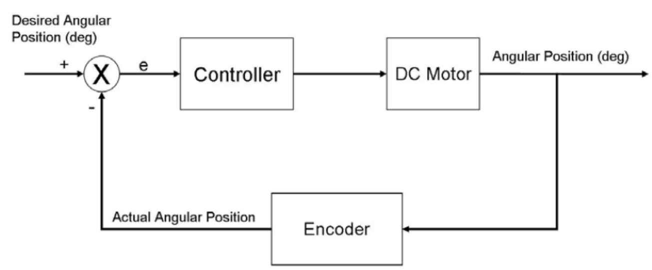

Fig. 2. Block Diagram of the DC Motor Position Control System

B. The Experiential Learning Approach

Learning through experience following the Kolb's model [18] has been promoted in several professional development programs designed for teachers [19, 20]. As learners, teachers gain new content knowledge and develop new teaching practice through experience. The main goal of these professional development programs is to equip teachers with new tools that can promote student engagement and learning. The basic experiential learning model follows three steps: (1) Experience: where participants experience or perform an activity, (2) Reflection: where participant reflect on the experience and develop an understanding of the outcome of the experience or activity, and (3) Generalization: where participants apply what they learned to new situations. In the experiential learning model, participants are actively involved in their learning. Moreover, the experiential learning approach can have an impact on solving complex problems [21].

The experiential learning process adopted in this case study is illustrated in Fig. 3 and is aimed at introducing teachers to control systems engineering through a series of experiments that are designed to allow the teachers to incrementally experience and understand various aspects of the project.

Teachers were presented with the experimental setup for the project shown in Fig. 4. Then, the hardware schematics diagram, shown in Fig. 5, was presented and discussed at the same time as the teachers were exploring the actual experimental setup. This approach made it easier for teachers to understand the interconnections between the different hardware components and what data and signals are being exchanged between two connected hardware modules.

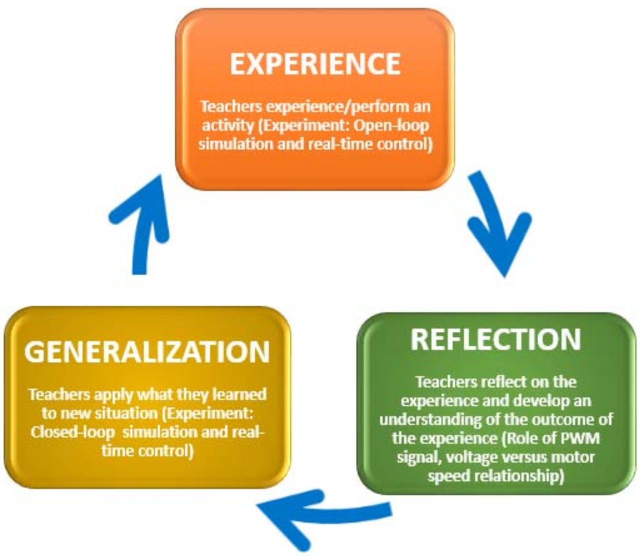

Fig. 3. The Experiential Learning Process to Engage Teachers in Control Systems Engineering

1) Experiment #1: Open-Loop Control of DC Motor

To understand the relationship between the voltage level applied to a DC motor and the speed of rotation of the motor shaft measured in rotations per minute (RPM), teachers duplicated an RT SIMULINK model that was used to control the speed of the motor in an open-loop configuration. Teachers were shown how to vary the voltage level by modifying the duty cycle of the signal that turns the power off and on to the motor. This exercise introduced teachers to the concept of pulse width modulated (PWM) signal. With the aid of a non-contact digital tachometer, teachers were able to measure the motor speed for various voltage levels. This experiment gave teachers a clearer and quick understanding of the mathematical relationship between the voltage level applied to a DC motor and the resulting speed.

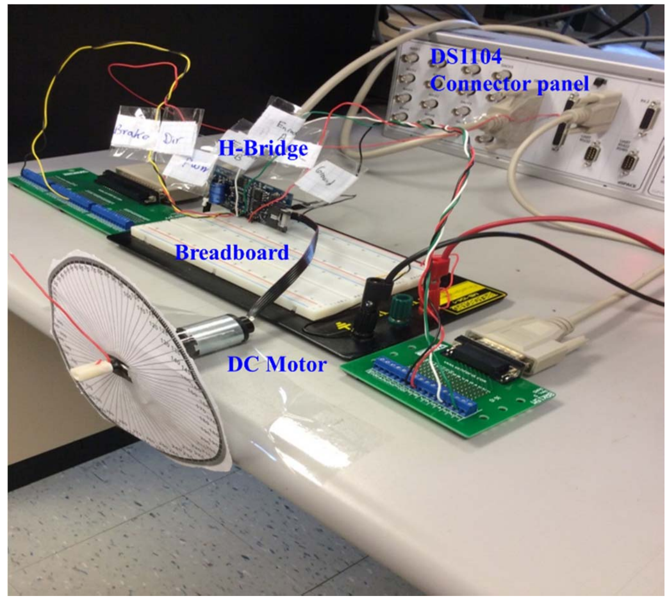

Fig. 4. Real-Time Experimental Setup for the DC Motor Position Control

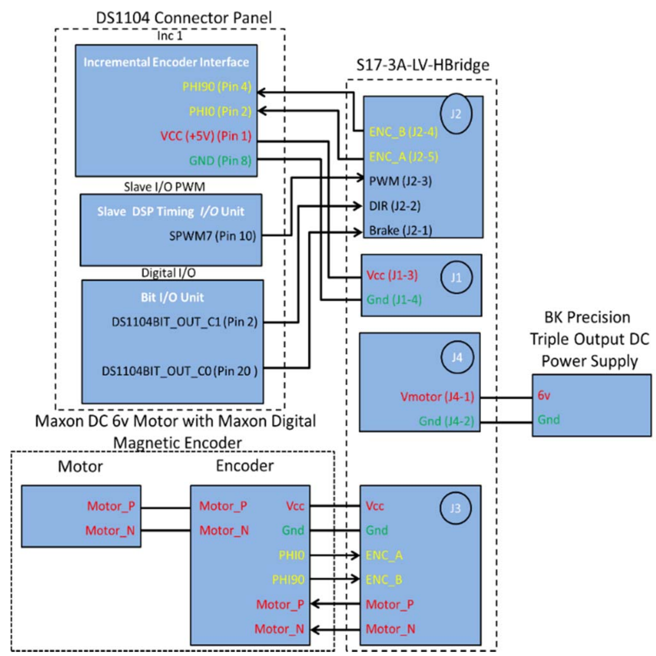

Fig. 5. Complete Hardware Schematics

2) Experiment #2: Off-line Simulation

Following the RCP method, teachers moved on to conduct off-line simulations of the position control of a DC motor (Fig. 6). A partially built SIMULINK model was provided to the teachers who had to add a few blocks to monitor salient system variables, such as motor speed, actual motor position, error signal defined as the difference between the motor actual angular position and the desired position. A block of a proportional-integral-derivative (PID) controller was provided to the teachers. To qualitatively understand the role of each PID control component, the teachers manipulated the gain values of the PID controller and observed the effects of those values on the system error. Through a trial-and-error procedure, the teachers managed to find a set of control gain values that resulted in minimum error signal and acceptable transient performance. An example of simulation results of the position control of a DC motor is shown in Fig. 7. The use of the SIMULINK model and digital scopes helped the teachers gain a quick qualitative understanding of how the system works, without dwelling on lengthy and complex mathematical derivations.

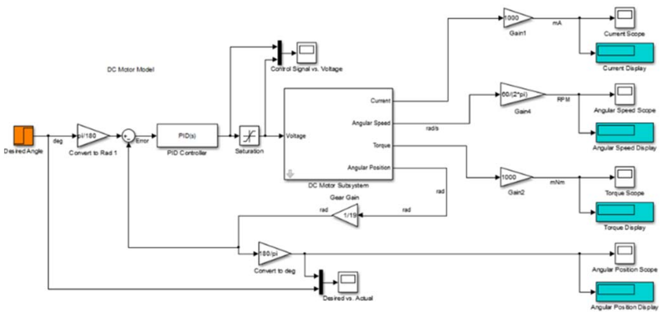

Fig. 6. SIMULINK *Model for Off-Line Simulation of the DC Motor Control System.*

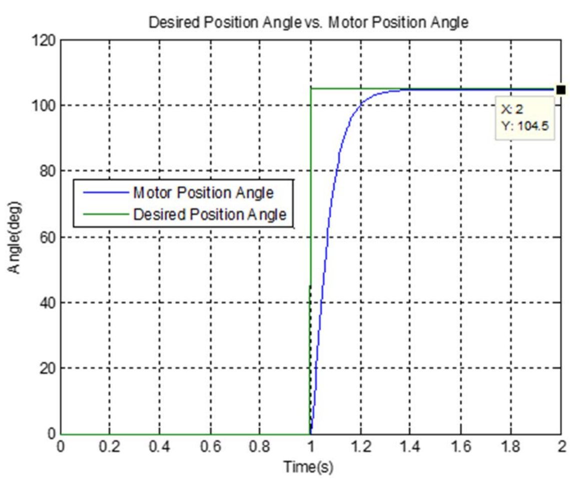

Fig. 7. DC *Motor Position Control Result (Desired Angular Position: 105º).*

3) Experiment #3: RT Angular Position Control

At this stage, teachers felt comfortable with various control design concepts and became familiar with the technical terminology used by control engineers. The final experiment for the summer project builds upon the previous experiments completed by the teachers. The process of modifying an off-line simulation model (Fig. 6) to obtain an RT simulation model to test the control algorithm on an actual DC motor was done by reflecting on what has been accomplished since the start of the project and revisiting the experimental setup (Fig. 4), the hardware schematics (Fig. 5Fig.) and the off-line simulation model (Fig. 6). Teachers concluded that in order to replace the SIMULINK model of the DC motor (Fig. 6Fig.) with the actual DC motor, information about the voltage level need to be sent to the external hardware and information about the motor speed and angular position need to be sent to the RT model. The reflection process was iterative and has led to the RT model shown in Fig. 8. A number of experiments were conducted. An example of the results of the regulation of the DC motor angular position to 180 degrees is reported in Fig. 9. Teachers were able to verify the actual angular position of the motor using a printed image of a 360 degree protractor attached the motor shaft (Fig. 4).

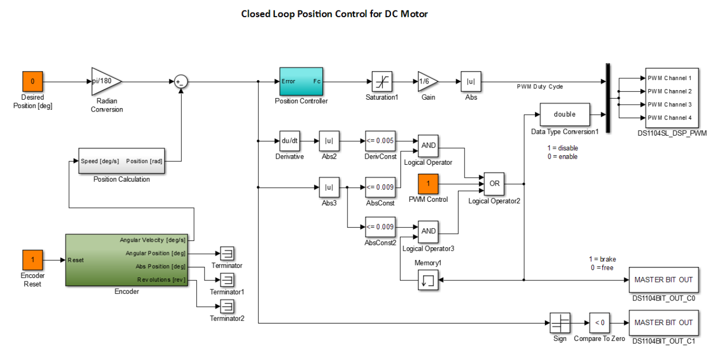

Fig. 8. SIMULINK RT Model for the DC Motor Position Control

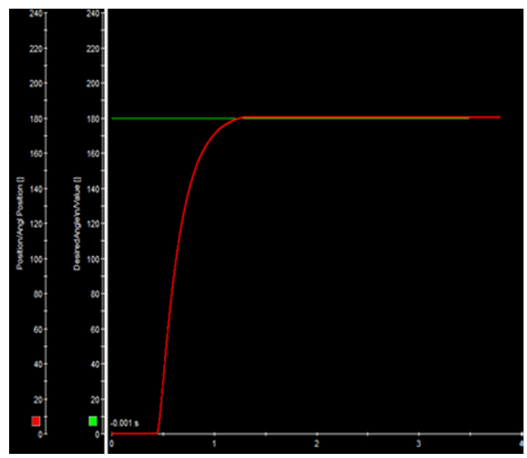

Fig. 9. Result *of the RT Position Control of DC Motor (Desired Angular Position: 180º).*

C. Identifying and Resolving Challenges

The engineering project presented challenges for teachers who have no prior engineering background. While the six week duration of the summer program is relatively longer than the average duration of other professional development programs designed for teachers, completing the project during the six week period could not have been possible without a carefully thought out strategy. The experiential learning approach was instrumental at every stage of the project. When teachers find difficulties understanding an aspect of the project, a demonstration using a simple experiment was presented for teachers to reflect on. The reflection period was followed by discussions between the teachers, leading to clarification of some aspects of the project objectives. Certain phases of the project required more time to complete than it had been originally anticipated. Hence, it was important to make the project schedule flexible and provide teachers extra time to complete their tasks.

IV. Hands-On Learning Activities for K-12 Classrooms

A. Translating the Engineering Experience into K-12 Classroom Activities

An important component of the summer professional development program engaged teachers in exploring and designing hands-on activities for their classrooms. The development of learning activities was an iterative process. The first step of the process was to formulate an engineering connection to the math and science concepts. During the early lesson development sessions, teachers discussed their research experiences and shared ideas for lessons with other program participants and the project management team. Supplies were acquired for teachers to experiment with the various design components of their new hands-on lessons.

To help in the design of the hands-on activities, teachers were guided to formulate concrete engineering connections to the science and math concepts taught in their lessons. With the gained engineering knowledge, teachers worked on identifying real-world engineering applications that demonstrate how engineers apply the science and math concepts to design new systems and solve engineering problems. As the summer progressed, teachers became more knowledgeable about the engineering research problems they were working on and were able to improve the formulation of the engineering connections to their lessons.

The teachers who participated in the control engineering project developed learning activities based on mobile robots. Key elements of the engineering project that inspired the learning activities are: (i) DC motors are used in the drive modules of robots, (ii) measuring angular position, and (iii) angular and linear speed calculations. The learning activities were developed as challenges where students play the role of engineers who are asked to solve a problem. The classroom challenges and learning objectives of the two lessons are given next.

1) Pythagorean Theroem (Grade Level: 10)

For the high school math lesson, the learning activity consisted of programming mobile robots to map the layout of a navigation course and calculate the angles of the layout corners. The learning objective is to calculate the length of an unknown side using the Pythagorean theorem. The learning activity not only teaches students about robots and how to program them, but also provide a real-world applications of the use of the Pythagorean theorem.

2) Calculation of Speed (Grade Level: 4)

This lesson was developed as an enrichment activity for fourth grade students. In this activity, students learn the concept of calculating the linear speed as the ratio of distance traveled over time. Working in groups, students calculate the speed of a LEGO ®MINDSTORMS®NXT robot that follows black lines of various lengths.

B. Observations of the Implementation of the Learning Activities in Teachers' Classrooms

During classroom observations, it is noted that teachers felt confident talking about their engineering experience to their students and providing qualitative explanation of how DC motors work. They also felt confident teaching their students how to program the mobile robots and relating the math concepts they are about to learn to real-world applications. The hands-on learning activity of the Pythagorean Theorem was implemented in Edinburg North High School (Edinburg ISD, Texas) and the activity on calculating linear speed was implemented in Romulo Martinez Elementary School (Sharyland ISD, Texas).

The implementation of each lesson was done over multiple periods. However, only one classroom observation was conducted by the program management team for each lesson. During the classroom observations, students showed excitement to work with the robots and collaborated within their groups on taking measurements. Students completed the worksheets developed for the lesson and answered the lesson challenge questions. While no formal surveys were conducted for students, the qualitative observations conducted in the classrooms revealed that students showed interest in participating in the activity and were highly motivated to complete the activity. This emphasizes the importance of relating math and science concepts to real-world applications and engaging students in hands-on activities to not only facilitate the learning of concepts, but also to increase student motivation to learn the concepts.

V. Conclusion

This paper described the engineering activities experienced by a team of teachers who were recruited to participate in a sponsored summer professional development program. More specifically, the paper presented an application of the experiential learning approach to systematically introduce teachers to the area of control systems engineering and work on control systems problems with increasing difficulties. Teachers participated in building, simulating, and real-time testing of a feedback controller for the regulation of the angular position of a direct current (DC) motor. As it has been observed during classroom visits, engaging teachers in engineering activities through a professional development program helps to increase teachers' confidence to teach challenging concepts and relate them to real-world applications.

Acknowledgment

The contents of this paper were developed upon work supported by a grant from the National Science Foundation (Grant CNS-1132609). However, these contents do not necessarily represent the policies and views of the National Science Foundation. Endorsement by the federal government should not be assumed.

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