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Hands-on Curriculum Teaches Biomedical Engineering Concepts to Home-Schooled Students

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***Abstract*—University level outreach has increased over the last decade to stimulate K-12 student interest in engineering related fields. Home schooling students are one of the groups that are valued for engineering admissions due to diligent study habits and high achievement scores. However, home schooled students have inadequate access to science, math, and engineering related resources, which precludes the development of interdisciplinary teaching methods. To address this problem, we have developed a hands-on, STEM based curriculum as a safe and comprehensive supplement to current home schooling curricula. The ultimate goal is to stimulate university-student relations and subsequently increase engineering recruitment opportunities. Our pre and post workshop survey comparisons demonstrate that integrating disciplines, via the manner presented in this study, provides a K-12 student-friendly engineering learning method.**

I. Introduction

HOME schooling is a growing form of K-12 education in North America. An increasing number of parents are taking educational responsibility for their children as they become dissatisfied with the public and private school systems. Many parents feel that it offers a unique one-on-one home instruction environment, which may contribute to an increased student academic performance on the Iowa basic skills test and the SAT as compared to their public schooled counterparts [1, 2]. Tools that are available to enhance learning for home schooling students include real time online learning interactive program and virtual classrooms, where instructors and students can come together in order to facilitate learning from a distance. However, home schooling does have limitations, such as limited funding and access to scientific technology, which makes it difficult for parents to integrate technical engineering based material into their child's curriculum.

Orsak discussed a shortage of engineering students and proposed an educational outreach K-12 program titled the Infinity Project. This project supplies K-12 institutions with the resources to educate students with an engineering curriculum in order to familiarize students with technical concepts prior to their undergraduate applications [3]. Callahan et al. expressed that a greater number of engineering students could be obtained through the recruitment of home schooling students. It has been suggested that in addition to their high achievement scores, home schooled students possess other valuable skills, such as the ability to learn independently from texts, making them even more valuable engineering candidates [4]. However, though these students are prime engineering prospects, most home schooling programs often lack facilities and technical resources needed to execute a hands-on engineering curriculum.

To facilitate home schooler-engineering interactions, we have developed a home schooling curriculum supplement, sponsored by the University of Wisconsin-Madison's (UW-Madison) student initiated Engineering World Health (EWH) Madison chapter [5]. EWH is a national organization that repairs modern medical equipment and facilitates its transfer to third world country hospitals [6]. The UW-Madison EWH chapter in collaboration with the Biomedical Engineering department has also integrated a student initiated community outreach program to stimulate K-12 interest in mathematics and science related areas. In these outreach programs we administer seminars and workshops to demonstrate the applicability of K-12 science and mathematics coursework into medical equipment used by health professionals. [5]. Recently, we have also begun to offer highly technical workshops to the home schooling community as a hands-on supplement to their engineering related textbook curriculum.

II. Hands-on BME Curriculum for Home Schooling Students

The hands-on curriculum supplements are built upon three pillars of the Delta program at UW-Madison, which include Teaching-as-Research, Learning community and Learning-through-Diversity. The Delta Program is a research, teaching, and learning community for faculty, academic staff, post-docs, and graduate students that helps current and future faculty succeed in the changing landscape of science, engineering, and math higher education [7]. We considered the limitations faced by the home schoolers in terms of limitation of hands-on technical experience as a research problem. As a result, the EWH Madison Chapter developed a supplemental curriculum to teach such students using biomedical engineering research facilities and evaluated its effectiveness using pre and post surveys. The EWH

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members who participated in teaching this workshop were biomedical engineering (BME) students who were interested in sharing their knowledge and experience. We formed two-fold learning communities where (a) current BME students provided instruction to the (b) home schooling families from different parts of the mid-west region using the UW-Madison BME instrumentation facilities. The hands-on engineering curriculum workshop in the BME laboratory combined the various disciplines: science, technology, engineering and mathematics (STEM) through concept integration as shown in figure 1 and facilitated learning through diversity of the teaching material.

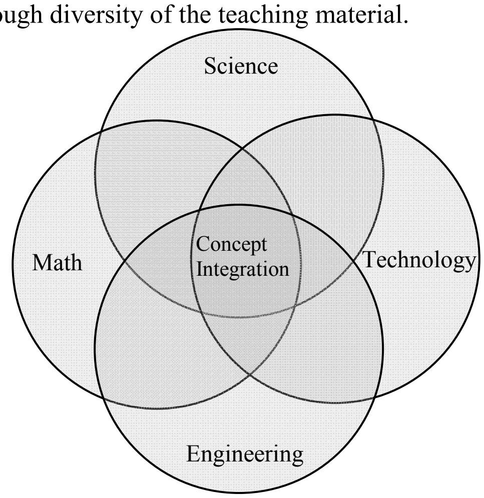

Fig. 1. Education model of STEM concept integration.

A. Stage 1: Introduction to Medical Technology

The STEM based home schooling curriculum supplement began with a hands-on demonstration of medical technology that measured different biological signals, ranging from the blood oxygen concentration to electrical signals elicited by the heart [5].

B. Stage 2: Introduction to Human Physiology

Once the students were familiar with the function of medical technology, we discussed the science behind the signals measured by the medical equipment. For example, one workshop focused on the electrocardiogram (ECG) technology, which continued into a discussion of the cardiac physiology behind the electrical signals previously observed. Once the electrical conduction pathways of the heart and contractile patterns of the cardiac muscle were discussed, the electrical 1 – 5 mV magnitude of the cardiac signals was brought to the student's attention.

C. Stage 3: Introduction to Electrical Engineering

To observe such small electrical signals, engineering design protocols had to be employed in order to appropriately solve the problem. Students proposed the use of amplifiers to increase the magnitude of the small signals for visualization. Facilitators of the workshop then discussed operational amplifiers and their role in technology.

Operational amplifiers were explained to the students

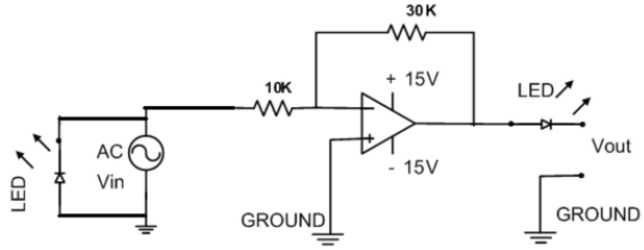

Fig. 2. Schematic of an amplification circuit for STEM home schooling curriculum supplement.

through the hands-on construction of a circuit utilizing wave form generators, amplifiers, LEDs, and resistors as shown in figure 2. Oscilloscopes were also used to demonstrate the wave form differences before and after the amplifier.

The purpose of the amplification circuit was to demonstrate that a small input voltage of 1.5 V (representative of the electrical cardiac signals), is insufficient to light an LED in parallel with the AC power source. However, that input voltage could be amplified (as in the case of the ECG) to a voltage that would be sufficient to illuminate the second LED in series with the amplifier's output. Thus, amplification of the input signal was determined by the students to be controlled by the circuit's operational amplifier and the resistors around it. Similarly, the minimal signals elicited by the heart could be amplified using multiple operational amplifiers.

D. Stage 4: Integration of Mathematics

The workshop also integrated mathematics into the electrical engineering section, which correlated to the science, technology and engineering aspects previously discussed in the workshop. Specifically, students used algebra to calculate the gain of different circuits and solved for different circuit component values to achieve an appropriate amplification of cardiac signals. Students then made adjustments to the circuit in figure 2 to achieve their desired gains and LED brightness. Students also used oscilloscopes to measure the input and output voltage waveforms, which were in turn compared to the mathematical outputs.

E. Stage 5: Integration of Stages 1-4

The workshop was concluded with an open discussion forum, in which students and parents asked questions about the program topics. This period primarily allowed participants to secure abstract connections between the workshop stages. Also, this allowed for instructors to provide more extensive explanations of medical technology, physiology, engineering, and mathematics, because all participants had undergone similar personal experiences with the material and established a working vocabulary of the concepts.

Students attending these workshops were middle school and high school aged students. The purpose was to integrate general concepts that they had already been exposed to (such as the concepts of division, electricity, the heart beat, and basic circuits like radio speakers) to help understand completely new concepts (such as gain, cardiac muscle contraction patterns, and operational amplifiers). Because these workshops are designed to work off of everyday experiences, like the heart in your chest, workshops were facilitated in an orientation such that all ages would have the ability to understand the context of the more difficult concepts.

III. RESULTS

The workshop integrates four major disciplines, which allowed the students to integrate the information in a more effective manner. The STEM home schooling curriculum supplement proposed in this study is such that the theoretical math and science learned by the students at home is applied and integrated in the laboratory setting, through practical and experimental examples.

Pre and post surveys were administered to the students in order to observe the efficacy of the integrated workshop principals. Results are shown in figure 3. During the workshop, students commented that they had gained new insight into how science, math, and engineering combined to produce technology. Furthermore, parents commented that the manner of subject presentation was very logical and helped them not only establish an understanding of the large amounts of information covered, but also a means to retain the information, as all of the concepts throughout the workshop built upon each other and were well integrated together.

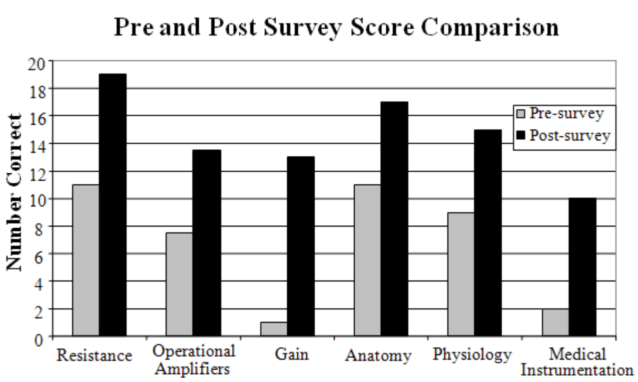

Fig. 3. Comparison of Pre and Post workshop scores. Pre-workshop surveys were given immediately prior to the workshop and post-workshop surveys were administered immediately following the workshop. Twenty students participated in this study.

IV. DISCUSSION

The pre and post workshop survey scores revealed that there was an increase in all tested areas. The most improvement came in the use of mathematics to solve a question regarding the gain of a circuit. The survey question identified as 'gain' in figure three was the following: *"If the input voltage of a circuit is 4V and the output voltage of the circuit was 8V, what is the gain of the circuit?"* This question integrated many of the STEM disciplines and students demonstrated in the post-workshop survey that they were more comfortable using mathematics for engineering related problems. Also from the post workshop survey, students indicated that they were now able to understand the importance of science and math in technology and medical devices.

The increase in post workshop survey scores can be attributed to the STEM integration curriculum and the large amount of hands-on interactions. The repetitive integration of all four disciplines allowed the students to continuously reinforce all of the newly learned concepts with other fundamental concepts. Not only did workshop activities require knowledge of math and engineering, but the ultimate health-related goals gave the students ambitions to learn the technical material. Some students said that the circuitry information was advanced for middle schoolers and high schoolers, yet *"circuits were easier to understand, because I could see my heart beat on the oscilloscope."*

Another essential part of the workshop curriculum was the biomedical hands-on activities, which might not be available to homeschoolers or schools with limited funding. When students outfitted themselves with ECG electrodes to visualize their own cardiac signals, they were more inspired to learn about the circuitry that made that signal visible on the oscilloscope.

Using similar methods, EWH – Madison Chapter also sponsors other STEM based K-12 seminars to public and private schools. Similarly, in these instrumentation seminars, students have expressed that it was easier to remember the engineering and mathematical concepts connected to physiological terms that they could see or feel themselves. Approaching the complexity of medical instrumentation in a biological orientation resulted in students becoming very interested in the topics. They were able to relate the functions of circuitry directly to their own experiences of daily life. For example, a number of students were able to understand that even through exercise, though they are consuming more oxygen, their oxygen saturation is regulated by homeostatic events, to ensure that all working tissues receive the needed amount of oxygen during the activity.

V. CONCLUSION

The positive survey score results from the workshops can be attributed to both the integration of technical material into a biological, personally-related application and the hands-on activities that allowed them to personally interact with the material. Also, the use of biomedical engineering laboratories to conduct the workshop provided the students with state-of-the art equipment and instructors, which home schooled K-12 students might not otherwise have access to. Furthermore, the UW student instructors also talked about the safety protocols of the electrical equipment, so that students and their families continue learning about circuits at home in a safe and effective manner.

This pilot study offers insight into the potential of integrative STEM education; however, more extensive studies must be conducted to determine the specific long-term impacts. To this end, we intend to conduct one and three month post-workshop surveys, as well as statistically competent feedback questionnaires. This will enable us to minimize short-term memory bias, decrease subjectivity of participant comments, and determine the long-term memory impacts of integrative instruction.

In the future, we also aim to develop a series of hands-on workshops that will be a monthly supplement to homeschooling curricula. Every month the supplement will address a different engineering concept, such as pressure sensors, thermistors, and pH devices. This will enable a fluid interaction between home schoolers and the UW-Madison biomedical engineering department for a long term interaction. This interaction will initiate a better engineering recruitment opportunities, as well as facilitate a hands-on learning environment for home schooling students.

With a regular schedule in place for the curriculum guided workshops, current engineering students will have many opportunities to be involved in the facilitation of those workshops. As such, the program will be sustained by the next generation of engineering students, who will be able to facilitate the curriculum supplements with the home schooling groups in the future.

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