Using BME to Teach High School Fluid Dynamics

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Abstract

In the VaNTH ERC, high school curriculum modules based in biomedical engineering (BME) have been developed. As part of this work a module on Hemodynamics has been developed based upon design principles growing out of cognitive science research. Accompanied by a figure and an audio file, the module begins with a grand challenge: "You, as a medical student, are presented with a patient with a heart murmur that can be heard throughout diastole. Listen to the audio file that accompanies this module to hear the murmur through a stethoscope. Pressure measurements made in the heart are shown below. Which valve and what condition are most likely to be causing this heart sound? Why?" Students investigate how the circulatory system works, how fluid dynamics principles apply to pressures and flow in the circulatory system, and how pressure patterns and heart sounds in the major valvular disorders are altered. A comparison of a Physics class using this curriculum (experimental) to an AP Physics B class who was taught the same principles through traditional teaching methods (control) was made. Students completed a short pre-test intended to measure basic understanding and a post-test composed of three parts: the pre-test repeated, more complex questions similar to a traditional test, and module specific "near-transfer" questions. On all three test sections, the experimental group significantly outperformed the control group ($p<0.02$) as measured by ANCOVA in the 2003-2004 school year. Additional field test studies are underway in the 2004-2005 school year. These results indicate that this biomedical engineering curriculum appears to have a positive effect on students' ability to master and apply fluid dynamics.

Introduction

The VaNTH Engineering Research Center for Bioengineering Educational Technologies is funded by the National Science Foundation (NSF EEC 9876363) as one of the several engineering research centers. While its focus is primarily at the undergraduate and graduate level of college education, a significant outreach program to the high school level exists. This outreach program, including an earlier NSF Research Experiences for Teachers (RET) supplement program, has involved the development of numerous curriculum modules for use in high school science classes.[1]

The design utilized in the curriculum modules makes use of a strong contextually based “Challenge” followed by a sequence of instruction where students would attempt to “Generate Ideas” (first thoughts on the challenge), view “Multiple Perspectives” of others commenting on

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the challenge and possible ways to address it, participate in extended "Research and Revise" activities where data and information would be gathered to help the student address the challenge, followed by "Test your Mettle" a formative self-assessment and "Going Public" where students solutions would be made public to peers and others. While having been implemented in a limited number of K-12 studies[2,3] results were positive for students working with this design, referred to as the "Legacy Cycle", by the developers.

Module Details

The Hemodynamics mosaic has as its grand challenge "You, as a medical student, are presented with a patient with a heart murmur that can be heard throughout diastole. Listen to the audio file that accompanies this module to hear the murmur through a stethoscope. Pressure measurements made in the heart are shown to the right. Valve disease is suspected. Which valve and what condition are most likely to be causing this heart sound? Why?"

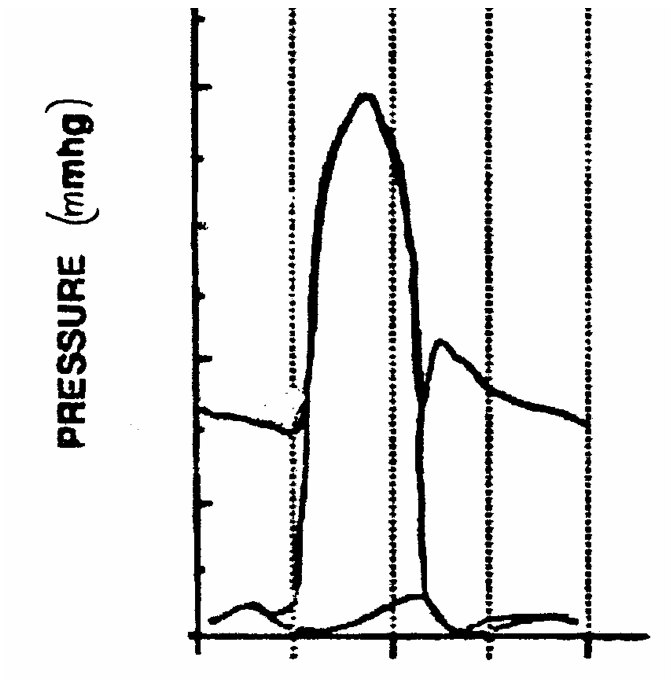

Figure 1. Pressure tracing from the patient's heart in the Hemodynamics Grand Challenge.

Challenge 1 focuses on the circulatory system as a whole. The second challenge investigates principles of fluid dynamics that are relevant in a study of the body's circulatory system. The third challenge links these topics together by asking about pressure versus time patterns expected in the major valvular disorders and what is responsible for murmurs.

From the traditional Anatomy and Physiology curriculum, students learn about the cardiac cycle as a whole as well as circulatory system anatomy in Challenge 1. This goal can be accomplished through traditional teacher lectures or through student use of the Interactive Physiology software package[4]. Students compare and contrast arteries and veins macroscopically and microscopically. To assess student understanding of the material covered in the first challenge, the students are asked to design a textbook chapter or infomercial on the circulatory system.

From the Physics curriculum, students learn fluid mechanics including pressure, force, specific gravity, Pascal's principal, Archimedes' principal, Bernoulli's equation, and conservation of mass

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and energy. Students participate in simple labs on numerous topics and complete problem sets for homework.

After listening to audio files on the heart sounds and various murmurs, students perform auscultation on themselves and take a partner's blood pressure. Students create an informational brochure about hypertension in which they must closely link the physics to the body. Additionally, students analyze cardiac pressure tracings of various valvular diseases and ultimately answer the grand challenge question.

This mosaic was designed for use in Physics and Anatomy & Physiology classrooms, though this study was only performed in Physics classrooms. As a whole this curriculum unit meets numerous state and national science content standards. This unit addresses the National Science Education Standards' Content Standard A that focuses on the student developing the abilities necessary to do scientific inquiry and understandings about inquiry. Content standards B, C, E, F, and G, are addressed through the module as students learn more about matter, energy, and organization in living systems; technological design; personal and community health; and science as a human endeavor. The American Association for the Advancement of Science's Project 2061 Standards are addressed also. In particular, the benchmarks for Physics Health, the Designed World, Habits of Mind, the Human Organism, and the Physical Setting.

Study Details

This small study was implemented using two classrooms: one Biomedical Physics class at a private school (N=17) named "experimental" and one AP Physics B class at a comprehensive public school (N=11) named "control." The AP Physics B curriculum includes a significant section on fluid dynamics, the basic science topic of the Hemodynamics Mosaic, making it an appropriate control classroom for this study. Both teachers are experienced Physics teachers. The experimental teacher is a co-author on this study and her classroom was selected first. The control classroom was chosen because of the rigor of the AP curriculum and its match to the curriculum level of this private school. Both classrooms contain a mix of genders (7 females in the experimental class and 8 females in the control class).

The pre-test items were measures of knowledge of the underlying concepts of the domain covered by the instructional units. The pre-test items included 7 multiple choice questions about basic fluids vocabulary and relationships. On the post-test items that had appeared on the pre-test were repeated first. It was expected that both experimental and control students would do rather well on this section of the post-test since the basic concepts that were tested were those that would have normally been taught in a Physics course. Secondly, a set of application type items were prepared that required the student to use basic concepts to solve a problem or answer a more complex question than was found on the first section of the post-test. These items were designed to resemble traditional, yet challenging to avoid having students top out on the test, chapter test types of questions. Topics included problems on Pascal's Principle, continuity equation, and Bernoulli's equation. The final section was a set of questions that were very specific to the module that the experimental students used, e.g., module specific. It was expected that students in the control group would generally not do very well on this type of question, due to its specific nature but it did allow some measure of how well the students in the experimental group had developed their thinking in regard to the module/mosaic that was developed. Control

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group students who were good at transferring knowledge would be expected to meet with some success on these questions however. These module specific problems were usually multiple step numeric or explanation questions that were meant to be somewhat difficult even for the students who had studied the unit.

In the experimental classroom, the pre-test and post-test were given immediately before and after respectively the use of the new Hemodynamics curriculum under study. In the control classroom, the pre-test and post-test were given immediately before and after respectively the use of traditional curriculum in AP Physics B on fluid dynamics. In both classrooms, students were required to work individually and without the help of notes or the teacher.

Results
The ANCOVA analysis method was selected to analyze the test results of this study[5]. Because students at the two schools may not have started with the same baseline of knowledge, the pre-test must be used as a covariate, a variable that represents a source of variation which has not been controlled for in the experiment and is believed to affect the experiment's outcome. The fixed factor was the group, experimental or control, in which each student belonged. ANCOVA adjusts the dependent variable so as to remove the influence of the pre-test on the post-test. The ANCOVA analysis will allow the null hypothesis that the treatment effects are not different when applied to individuals with the same baseline test score. In other words, if we were to start with identical students in each group would the Hemodynamics curriculum better teach the principals of fluid dynamics than traditional AP curriculum?

The results of each of the three sections of the tests (pre-test items repeated, application items, and transfer items) are shown in Table 1 below. The p-value shown reflects the results of the ANCOVA analysis completed on that section of the post-test using the pre-test as a covariate.

Table 1. Hemodynamics Mosaic Test Results

	Experimental Mean	Control Mean	Max Points Possible	P-value
Pre-test Items	4.14 ± 0.25	3.06 ± 0.32	7	<0.02
Application Items	9.51 ± 0.87	0.31 ± 1.09	25	<0.001
Transfer Items	2.49 ± 0.39	0.11 ± 0.49	10	0.001

Interpretation
These results indicate that this BME curriculum appears to have a positive effect on students' ability to master and apply fluid dynamics. Students in the experimental group performed significantly better than control students on tests of basic fluid dynamics vocabulary and concepts as well as on traditional test-type problems of the basic physics. Students in the experimental group were also better able to apply their new knowledge to near transfer problems, though one might expect that given the nature of the transfer questions. In these types of studies the claim that the application and particularly the transfer items are too different from the experiences that the control group might have in their regular classes is a concern. Even considering this possibility, the differences between the groups on the pre-test items is sufficient to indicate a difference in instructional design was a significant factor.

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Additional field test studies are underway in the 2004-2005 school year to include additional Physics classrooms as well as to introduce new Anatomy & Physiology tests and classrooms. These additional studies will help to verify the results of this small study.

Studies such as this and others in the literature[1] indicate that both challenge-based curriculum and curriculum based in an applied topic such as biomedical engineering may significantly improve students' mastery of the basic science. Through the use of the challenge question, students are better to able why they are studying basic science as they are forced to apply it immediately to some real world problem. Materials based in engineering also allow secondary students the opportunity to be exposed to engineering as a possible field of study and employment. These suggestions have ramifications for the design of future high school science curriculum and should be considered carefully.

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