# Biomedical Engineering Topics in High School Science Instruction: Initial Development and Field Studies

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## Theoretical Basis

The growth of the influence of cognitive science on the design of instructional materials in science and mathematics has been substantial over the past twenty years. Early works such as Bransford, Sherwood, Vye and Reiser[1] summarized research on teaching thinking and problem solving pointing out important differences between the organization of knowledge by experts versus novices in classical problem solving domains such as chess[2] as well as in physics[3,4]. Another important area highlighted by Bransford, et al. was the experimental evidence that while students may have acquired knowledge in previous learning it is not always accessed when needed[5,6]. This inability to access applicable knowledge in a wide variety of domains was mentioned as early as Whitehead[7] who used the term "inert knowledge" to describe this type of knowledge. Additional work seemed to indicate that traditional educational methods tended to produce knowledge that remained inert.[8]

These concerns led researchers to propose alternative instructional methods that attempted to create macro-contexts for students in order that knowledge learned might be used in new settings rather than remaining inert. Studies in science[9] as well as mathematics[10] and literacy[11] pointed towards the effectiveness of such instructional designs. This also led the researchers to jointly propose a name for this general type of instructional design, "Anchored Instruction"[12,13]. As noted in Bransford[12],

> "The model [Anchored Instruction] is designed to help students develop useful knowledge rather than inert knowledge. At the heart of the model is an emphasis on the importance of creating an anchor of focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems." (p. 123).

Schwartz, Lin, Brophy, & Bransford[14] have extended the Anchored Instruction concept to a "flexibly adaptive design" which called for:

> "Methods used by teachers and learners that are constrained enough to be consistent with important principles of learning and instruction, but that are also

> flexible enough for teachers to be creative in tailoring instruction their own strengths and learners' and community's needs." (p. 185).

The design 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 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. Examples of implementation of this design include Schwartz, et al.[14] and Sherwood[15].

Several other research and development groups have developed materials and/or programs that have been influenced by some of this early work [16,17,18,19,20]. While the details of each program have differences, especially in the types of outcomes that are expected of students (designs of objects vs. solution of a challenges based upon real or simulated data) they do have common threads. They all use a rich contextually based problem/challenge to start the instruction and affordances for students to engage in study at a substantive depth into the problem/challenge, reflect on their work, obtain formative assessment, revise thinking and present the products of their labors. Summary documents such as Bransford, et al.[21] have provided additional examples of such types of designs, as well as expansion of the theoretical basis for such designs.

## Materials Development

The development of the materials produced for this project was part of a larger multi-university project, the VaNTH Engineering Research Center for Bioengineering Educational Technologies (VaNTH ERC). The VaNTH ERC is a multi-year, multi-institutional program with the aim "… to integrate learning science, learning technologies, and the domains of bioengineering in order to develop effective educational resources to prepare for the future of bioengineering." An overall description of the VaNTH ERC may be found at its website (www.vanth.org).

The National Science Foundation funds supplementary grants to NSF grantees that want to involve classroom teachers in their research through the Research Experiences for Teachers (RET) program. Funds support teachers working with researchers on their projects both in summers and during the school year. Dissemination of faculty research, when appropriate, to the cooperating teacher's students is strongly encouraged as a way for students to learn about the research activities of academic scientists and engineers. The VaNTH ERC obtained RET funds to allow secondary school teachers of physics, chemistry, and advanced biology to come together with university faculty in both biomedical engineering and education, to consider how concepts taught in college level biomedical engineering might be transferred to the secondary school level.

In the summer of 2001 and during the school year 2001-2002, five curriculum modules were developed and field tested. The topics of these modules included the biomechanics of balance; the biomechanics of the iron cross position in gymnastics, medical imaging with a focus on ultrasound, the energy systems of swimming, and the electrocardiogram. The balance, iron cross, medical imaging, and electrocardiogram modules were designed for use in the Physics classroom. The swimming and electrocardiogram units were designed for use in the biology or Anatomy & Physiology classrooms.

The instructional design of the curriculum modules was based upon the design features of the Legacy cycle previously mentioned[14] and the overall "How People Learn" (HPL) framework presented by Bransford et al.[21]. A short description of each curriculum unit is provided.

The electrocardiogram mosaic began with the following grand challenge question, "Suppose one of your teachers visits his doctor and, as a part of a routine exam, he has his electrocardiogram (ECG) measured. The results are shown below. Should your teacher be concerned about these results?" After initial brainstorming by the students, the mosaic was broken down into three legacy cycle modules. Challenge 1 focused on how the heart beats and why. Challenge 2 focused on what the normal ECG measures and what information is reflected on the normal ECG. Challenge 3 focused on how the ECG reflects abnormalities of rhythm and structure. Major topics of the typical Physics and Anatomy & Physiology courses that are included are the following: cardiac cycle, cardiac anatomy, the heart's intrinsic conduction system, the cardiac action potential, electric fields, dipoles, basics of the electrocardiogram, and vector projections.

The Iron Cross module is among the shorter curriculum modules, taking place in a little over a week. This module's focus is primarily on torque. Students learned how muscles generate forces and how different muscle groups create different types of movement. They created free body diagrams to represent the situations and calculate, using vector components and toque, whether or not a particular person could maintain the iron cross position.

The Balance module begins with the following challenge question, "Your grandmother is recovering from a recent right hip injury, and she needs to learn how to use a cane to help her maintain her balance. In which hand should she use the cane and why?" The module then leads the student through a study of forces, Newton's Laws, free body diagrams, equilibrium, and torque. Much attention is paid to the concepts of center of gravity and stability. Students calculated the center of gravity of their own forearm and of their entire body.

The Swimming module focuses on the energy systems of the body and their measurement through the context of designing practices and analysis for a high school swim team. The grand challenge reads, "How can a swim team coach best determine the physical condition of his/her team throughout the season? How can he/she modify practices to best meet the needs of the individual swimmers? How can an individual swimmer chart his or her progress during the season?" Specifically students learned about specificity of training, glycolysis, Kreb's cycle, oxidative phosphorylation, lactate production and accumulation, and non-invasive measurement of physical fitness. This module involves a high level of independent student research and design.

The Medical Imaging mosaic is one of the longer mosaics. It begins with the grand challenge, "A medical student has palpated a foreign mass in a patient's abdomen. In order to determine the urgency of further medical procedures, the medical student would like to know if that mass is cancerous or not. The medical student would like to minimize the invasiveness of any testing procedures. How could the medical student accurately locate the center of the mass and know exactly where to insert a biopsy needle? Furthermore, could the student avoid using a biopsy needle at all?" Challenge 1 addresses what type of non-invasive imaging systems presently exist and how they work. Challenge 2 focuses on how sound can be used to see into the body. Lastly, Challenge 3 allows students to explore a presently unanswered question in medicine, "Could the student avoid using a biopsy needle at all?" This mosaic includes many topics normally covered in a physics class including the basic properties of waves (frequency, wavelength, transverse vs. longitudinal, wave speed in different materials, the wave equation, power, intensity, decibels, Doppler effect, and interference), radiation, positron emission, and some magnetism. Students also learn abdomen anatomy, organ level cellular differences, and the properties of a cancerous cell.

## Field Testing

A fuller discussion of the field study and analysis is provided in Sherwood & Klein[22], however, a summary is provided here. In the 2001-2002 school year, each of the modules was used by at least one of the five teachers who had been on the development team. Most of these classrooms were regular level physics classrooms with the addition of one accelerated physics classroom. A specialized class entitled 'Biomedical Physics' was used to field test four of the five modules.

The design of the field testing evaluation was a classical pretest- posttest control group design using intact classrooms. Control group classrooms came from physics and/or advanced biology, anatomy & physiology classrooms in the same school as the experimental classrooms or similar classrooms in other schools. Given the use of intact classrooms, the pretest was used as a statistical control, through the ANCOVA analysis method, on the variation in students' pre-existing knowledge about the subject matter under study. Students in the experimental condition took the pretest exam before they began an instructional unit and the posttest immediately after they finished the unit. Students in the control condition took the pretest before instruction in the general topic that served as the conceptual basis for the experimental unit. The instruments used in the study were designed by the team which developed the instructional units and were constructed of two major parts. The pretest items were measures of knowledge of the underlying concepts of the domain covered by the instructional units. The pretest items were a multiple choice, short answer, or relatively simple computational problem and varied from 8 to 12 separate questions. The posttest measure contained the exact same items as the pretest measure plus an additional one or two items that were designed as "near transfer" type items. These items were designed to see if students could apply the conceptual knowledge that was learned either in the instructional unit or control condition to a problem situation that was similar to but not identical to problems that were part of the instructional unit or control instruction.

For three of the five instructional units (Balance, ECG, & Swimming) there was a statistical difference between the control and experimental groups, favoring the experimental group, using the ANCOVA analysis. Effect sizes (E.S.) ranged from a medium (0.40) to a large (1.74) level for those units that had statistical differences. For the "near transfer" items, the differences between experimental and control groups were apparent for each of the five units. Effect sizes ranged from medium (0.42) to very large (3.95).

## Discussion

The statistical analysis shows that the use of the instructional units appears to have a positive effect on students' ability to answer questions both on the basic conceptual knowledge of the particular content area under study as well as "near transfer" items. This appears to be consistent with other projects that have used instructional approaches that use a contextually rich problem based approach to instruction[15,16, 17, 18, 19, 20]. Such programs provide a context that allows students to see both the "worth" of studying the materials and a goal that they can accomplish. They are also consistent with the instructional designs presented by Bransford, et al.[21].

As is the case with field based research of intact classrooms there are variables that cannot be controlled and therefore can offer alternative hypotheses for the seen results. Instructional time is one of these variables that could not be controlled within this experiment. While teacher self reports of classroom time spent on instruction in both experimental and control classrooms indicated a general match in instructional time between the groups, the differences in emphasis placed upon particular concepts could not be controlled completely and therefore students in experimental classrooms may have received more focused instruction on concepts that were measured by the instruments of the study. Additionally, the "halo effect" of using new novel instructional materials of a somewhat different than "normal" instructional sequence, could not be controlled for given that the control condition was "normal" physics instruction.

The use of instruments of relatively short length which were created by the developers of the experimental units is also somewhat suspect. While review of the instruments was undertaken by several secondary physics teachers and well as university faculty, these persons were also part of the development team. The "near transfer" items may have been especially troublesome due to the fact that they were generally grounded in the context of the instructional unit, which may have not been familiar to the students within the control group.

Even considering these alternatives, it appears that the instructional design elements used and the modules implemented have substantial potential to improve science instruction at the secondary level. Additional field testing of current modules plus the development of new modules, e.g., "Hemodynamics" are underway to verify and extend the results reported here.

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