AC 2010-1361: DESIGNING, BUILDING AND ANALYZING MUSICAL INSTRUMENTS AS A GATEWAY TO MATHEMATICS, SCIENCE AND ENGINEERING FOR PRE-SERVICE EDUCATION STUDENTS

Robert Culbertson, Arizona State University

Robert Culbertson, Associate Professor of Physics, is directing the Music in Motion course and leading the development and teaching of the physics portion of the course. In addition to the science of sound, he has a deep interest in music appreciation and performance; he has played classical guitar and other stringed instruments for forty years. Prof. Culbertson works extensively with in-service science and math teachers. This includes leading the development a course in connecting physics, chemistry, and mathematics in an NSF-funded Math-Science Partnership grant; serving as Director of the Master of Natural Science (Physics) program at ASU, including ASU's Modeling Workshops and other summer courses; and leading a new summer research experience for forty math and science teachers project, funded by Science Foundation Arizona. He is also actively involved in a pilot project to provide a compact path to teaching certification for mainstream math and science majors. He has directed an NSF REU program in condensed matter physics, and he is actively involved in undergraduate education, including the teaching of the introductory courses for majors. His experience in teaching and expertise in physical science, math, and music makes him well qualified for leading the Music in Motion project.

Dale Baker, Arizona State University

Dale Baker, Education Professor in Curriculum and Instruction with 25 years of experience in science education research and teaching, is assisting in the assessment and evaluation of the project, a role for which she is well suited from her many years of experience in teaching and conducting research in assessment. She is helping organize the structure of the research and the data collection and analysis processes of the project. She is also providing the connection to the science teaching and learning research community, with her most recent connection as 5-year co-editor of the Journal of Research in Science Teaching. She has experience in the evaluation of a number of NSF projects including a Bridging Engineering and Education and a current TPC program. She has been a faculty member in science curriculum and instruction and has taught and developed courses in assessment, equity, and bridging engineering and education. She has been involved in the development of innovative science teaching curricular activities and is a co-PI of an NSF TPC project that is providing community college science teachers with authentic science inquiry and writing experiences. She is contributing to the effective formative and summative assessment of self-efficacy and learning of students in the course, which is critical in structuring of the Music in Motion course and measuring its impact on students.

Janice Meyer Thompson, Arizona State University

Janice Meyer Thompson, pianist and Professor of Music, has identified and is leading the exploration of the characteristics of musical instruments from the viewpoint of a musician. At ASU, she is keyboard area coordinator, and founding director of the Piano Prep/Conservatory Program. She has three decades of national and international performance experience as a solo and collaborative pianist, lecture-recitalist, and master class clinician. Her extensive performance career includes collaboration with a wide variety of instrumentalists and singers. She is nationally recognized for her leadership in the field of piano pedagogy and teacher training and is chair of graduate programs in pedagogy in the School of Music. For 20 years she has directed the ASU Piano Prep Program, an instructional program pairing pre-college age children with graduate students and selected community teachers. Her contributions on the difficult or impossible to quantify subjective side of musical instruments are balancing the methodical physics, math, engineering, and technical writing components of the Music in Motion course.

Christopher Mehrens, Arizona State University

Christopher E. Mehrens, Head, Music Library, serves a librarian to the Music in Motion course. He arrived at ASU in 2007 after having served on the library faculty at Indiana State University. In addition to a Masters of Library Science with Specialization in Music Librarianship (Indiana University, Bloomington) he also holds a Ph.D. in Historical Musicology (UNC-Chapel). In 2006 he was the recipient of the Walter Gerboth Award and was also recognized as a promising scholar by Indiana State University for his research on music criticism in the United States. At Arizona State University, he is responsible for managing all aspects of Music Library operations and contributes to the management of the Arizona State University Libraries. His expertise, both as an information professional and as a musicologist makes him eminently qualified to provide library support to the Music in Motion project.

Stephen Krause, Arizona State University

Stephen Krause, Professor in the School of Materials, is leading the development and teaching of course content in the area of materials and their properties in musical instruments. He arrived at ASU in 1981 after completing his research on polymer deformation at the University of Michigan. Since then related courses he has developed and taught include Materials Characterization, Polymers and Composites, Materials Capstone Design, and Bridging Engineering and Education. He has developed innovative learning tools such as Materials Mentor Fold Out Notes, Materials Lecture Work Notes, and Materials Lecture Activities. He has also co-developed learning assessment tools including a Materials Concepts Inventory and a Chemistry Concept Inventory. His technical research is in nano-characterization of polymers and semiconductors and his educational research is in learning in engineering education and in K-12 engineering outreach. He has developed and taught new science and engineering content for courses in a NSF Math Science Partnership, Project Pathways. He also supported by NSF developing new content, technology, and assessment for understanding student learning and misconceptions in the broadly subscribed Introductory Materials Science course in engineering. The course will employ Concept in Context and Classroom Clicker assessments to provide rapid formative feedback to students and instructors. His expertise and experience will help in integrating the math, physics and technical writing as embedded in the engineering design process in the Music in Motion course.

Engineering Design of Musical Instruments as a Context for Math, Physics and Technical Writing in a Freshman Learning Community Course

Abstract

In order to enhance technological literacy and to integrate math, science, and technical writing into a contemporary context, a new math-science block course, Frets, Flutes, and Physics, for freshman at Arizona State University has been developed. The inquiry-based course is in an Academic Success Cluster and consists of an 11-credit hour course to satisfy basic math, laboratory science and English requirements. The course has been developed and has been taught by an interdisciplinary team consisting of a physicist, mathematician, engineer, educator, musician, and science teacher. The context for the math, science, and technical writing was the design and building of musical instruments. Students used the engineering process to design, construct, and demonstrate instruments. Additionally, a music school faculty and music librarian arranged weekly integrated sessions demonstrating the history, culture, physical features, and musical character of a wide variety of instruments played by local professionals and graduate students. The course was assessed with respect to changes in technological literacy, problem solving ability, and creative thinking and as a result of the project. The goal was to integrate the physics, mathematics, and technical writing to understand and quantitatively and qualitatively describe the sound of music as well as design and build musical instruments using the engineering design process. Initial attitude results indicated that the students have low interest in physics and math and high interest in music and took the course because of musical interests and to fulfill university core class requirements. Details of demonstrations, instruments constructed, barriers and affordances to learning, and assessment results will be shown at the conference.

Introduction

Most science, technology, and math classes lack connections and coherence to one another and to the context of people's daily lives. While college courses that tap into personal interests, such as music, food, recreation, and art are usually well subscribed, they rarely touch upon Science, Technology, Engineering, and Mathematics (STEM) topics. However, if technical learning and problem solving skills were embedded in the technical aspects of a course subject focused on a personal interest area, such as music, relevance would be high and motivation would be quite positive, if well taught. For good teaching, the general theoretical underpinnings which are based on the principles of effective learning are found in *How People Learn*[1], *Knowing What Students Know*[2], and *How Students Learn*[3]. The materials developed were "learner-centered, knowledge centered, assessment centered, and community centered." This was done by developing, teaching, and assessing a course which integrates required courses in mathematics and laboratory science for liberal arts and fine arts majors. It used inquiry and project based learning of the math and science content that was embedded in the engineering design process with a context of the STEM of music and musical instruments. Thus, connected and contextualized STEM learning was taught that emphasized both utilitarian and inquiry based motivations—where learning was conceived as fun and exciting, and was made relevant to students' lives.

The context of musical acoustics has been used to bring math and science into the classroom at levels ranging from elementary school to upper division college undergraduates. Music is of almost universal interest to students, as demonstrated, for example, by the ubiquitous presence of personal digital audio players, such as the iPod. Many university students, regardless of major, are themselves music makers as amateur (or sometimes professional) musicians. Exploiting students' interest in music provides a vehicle to teach fundamentals of math and science in STEM education.

This project has taken this idea much further by combining math, science, and engineering design in a block course that satisfies basic mathematics and science requirements of all students at Arizona State University. The project built both on students' interest in music and their need to take math and laboratory science courses to fulfill university requirements. An eleven-credit math-science-English course was offered as a Learning Community. ASU's learning communities are developed and supported within the College of Liberal Arts and Sciences (CLAS). Learning community courses are marketed to all 4000 incoming freshman CLAS students through initial advising; this project's course was open to all ASU freshmen.

As a minimum requirement, all ASU students must complete three credits of an approved mathematics course and four credits of a laboratory science course and two semesters of 3-credit hour English. The curricula for STEM majors naturally satisfy these math and science requirements. By offering the learning community in this project, STEM majors are essentially filtered out, and the targeted students will mostly consist of non-STEM majors. Thus, non-STEM majors are selectively recruited at the very beginning of their college careers. This project provides an opportunity to attract students into a STEM major by demonstrating the importance and beauty of math and science in an area of personal interest to them.

The course in this project was team-taught by English, math, science and engineering faculty members. Although it was anticipated the course would be very popular because of the hands-on studio approach, the perceived daunting rigor of the math and science cause enrollment to be 7 students, far short of the 30 possible students. It will be offered again in fall 2009. Research driven inquiry-based instruction was used for teaching so that students had to investigate and discover for themselves many of the fundamental behaviors of vibrating systems. Mathematical support, based on fundamental understanding of the mathematical notion of a function, as well as mathematical modeling supported the science. The final portion of the course involved the engineering design process, where students applied what they have learned to design and construct a musical instrument. There they found out that applying the theories they learned first results in a poor or non-functional instrument, but through iteration and refinement instrumentation improved and they developed a deeper appreciation for the math, science, and engineering design. At the end of the course the 7 students gave a "concert" on instruments they had designed and built themselves.

Project Research Questions.

The research questions addressed in this work were the following. How good is the learning effectiveness of a cross disciplinary math, science and engineering design course with real world context of music and musical instruments? How effective was change for student affective attributes of tinkering and technical self efficacy and future professional impact and of the cognitive attributes including conceptual change in precalculus and physics of sound, as well as change in problem solving skills and understanding the engineering design process? What was the impact of the cross-disciplinary *SEMI-STEM* course on learning and motivation of *all* students in terms of technical literacy and problem-solving, decision-making, and creative-thinking skills necessary to be competitive in tomorrow's world?

Background

Global Competition in a Technological World

"...Society now faces critical global-scale issues that are fundamentally technical in nature—for example, climate change, genetic modification, and energy supply. Only a far more scientifically and technically literate citizenry can make wise decisions on such issues. Second, modern economies are so heavily based on technology that having a better understanding of science and technology and better technical problem-solving skills will enhance a person's career aspirations almost independent of occupation. Furthermore, a modern economy can thrive only if it has a workforce with high-level technical understanding and skills." So state Wieman and Perkins in their 2005 critical, but hopeful, essay, "Transforming Physics Education." At Arizona State University (ASU), as part of a liberal education, and to promote technical literacy and cultivate creative thinking and problem solving skills, it is required that all undergraduates take a minimum of two laboratory-based science courses and two mathematics courses. However, at ASU, and at most other institutions, mathematics, science, and technology-related courses, such as engineering, are usually not effectively taught from a contemporary pedagogical perspective that employs the latest research findings on teaching learning.

Ineffective Math and Science Instruction.

Some of the issues about ineffective, traditional teaching include the following. Content is delivered via lectures instead of engaging learners. There are few courses that frame content in the real-world contexts of students' lives. Courses more often than not are unconnected to prior, current, or subsequent courses with content related between courses. Performance in courses is, to a great extent, usually measured based on memorization and algorithmic problem solving skills, rather than a deep conceptual knowledge of the subject matter. Students' prior knowledge is rarely acknowledged or understood in designing instruction and, as such, robust misconceptions persist and inhibit conceptual change and effective learning. The net result of all these factors is to negatively impact the potential for students' success in their future personal and professional lives. In contrast to this dismal perspective, there is the growing knowledge and awareness that research on teaching and learning is revealing new pathways to significant improvements in more effective learning at institutions of higher education.

Student Attitude and Self-Efficacy

Undergraduate students may have negative attitudes about taking STEM courses because they lack self-efficacy and may experience considerable personal anxiety about technical subjects such as math and science and technology/engineering, as well as tinkering anxiety about laboratory activities. Many students perceive a lack of societal relevance of math and science and technology/engineering to themselves and their future lives and professional activities (Adelman, 1998). This lack of societal relevance refers to the relationship between technological products and services that improve individual lives and the benefits to society and the environment, e.g. high-tech prosthetic devices that allow amputees to climb mountains or energy efficient appliances that conserve resources. Women would be more attracted to engineering if they felt that their social goals could be met by studying engineering. As such, women do not persist toward STEM careers because they do not see the social good of a possible career choice in STEM. The combined effects of low self-efficacy, lack of societal relevance, and traditional teaching methods, creates barriers to students taking coursework that might benefit their future skills, perspectives, technical literacy and problem solving skills.

Math & Science Embedded in Engineering Design for Inquiry & Project Based Learning.

One of the most frequently employed and most effective models of pedagogy is inquiry learning, which engages students in the educational process, and which has been shown to effectively promote conceptual change and learning. However, inquiry learning is often delivered in an abstract framework that is unconnected to students' lives. Another effective model is project-based learning (PBL), which addresses this issue with an instructional strategy that uses real-world situations and/or open ended problems identified by learners and which also has many possibilities for design and development of projects[4, 5]. PBL has great potential for showing relevance of technical problems to society and students' lives through real-world contexts and problems of interest to minorities and females. PBL encourages students to ask meaningful questions, to gather and evaluate evidence, and to propose alternate solutions. It also facilitates a student's inquiry into what they know, what they need to know, and what they and others value. PBL is also well suited for longer-term group activities that provide opportunities for hands-on activities which build tinkering self-efficacy.

This project used the engineering design process to specify the projects on musical instruments that provided the context for the course. This supported students employing problem-solving, decision-making and creative-thinking skills, all of which are considered important for competitiveness in the global economy. Briefly, the engineering design process consists of a series of steps which include: 1) identify and define a need or a problem, 2) specify requirements and constraints, 3) brainstorm to propose possible alternative solutions to the problem, 4) fit models of physical phenomena and associated mathematical models to the alternative solutions; 5) use the decision making process to select the most viable solution based on the specified requirements and constraints; 6) construct a prototype physical model; 7) evaluate the performance and behavior of the model; 8) refine and iterate the model if necessary; and 9) communicate the solution and its basis. The selection, design, fabrication, and physical and mathematical modeling and testing of musical instruments was the real-world context which was the basis for learning the physics and math which can model and predict the behavior of the instruments. The inquiry learning and project based learning are connected to and embedded within the engineering design process. When the terms of Science and Engineering of Musical Instruments (SEMI) are connected with Science, Technology, Engineering, and Math (STEM) this model approach to teaching and learning is known as *SEMI-STEM*.

Social Learning Theory as the Model for Learning in the *SEMI-STEM* Course.

The theoretical underpinning for the teacher training in this project was Social Learning Theory[6]. According to Bandura, one of the fundamental ways in which learning occurs is through observation and then imitation of that observed behavior. The basic premise of social learning theory is that "modeling influences produce learning principally through their informative function. During exposure observers acquire mainly symbolic representations of the modeled activities which serve as guides for appropriate performances" [7]. To transform observational learning into performance, four processes occur: (1) Attentional Processes—closely observing the demonstrated behavior; (2) Retentional Processes—creating a mental representation in symbolic form of the demonstrated behavior; (3) Motor Reproduction Processes—the learner attempts to behaviorally enact the observed, demonstrated behavior; and (4) Motivational Responses—immediate feedback on the behavioral performance. In 1997, Bandura[8] added to what constitutes motivational responses when he stressed that individuals are most likely to adopt the modeled behavior if it results in outcomes they value. In this study, students were not only be given the basic facts and information they needed to use *SEMI-STEM* models, they were also be immediately involved in hands-on lab experiences. The instructors provided the students with constructive feedback to help them learn more effectively. The value placed on this learning was enhanced by class discussions of the use of models in the *SEMI-STEM* approach as well as how these types of activities can impact the students' self-confidence and professional career interests. Design is a neglected context for learning science and design activities not only help students learn science content, but also engage students in scientific discourse[9]. We found that the design process had to be embedded in a student-selected design project, experience using design tools, and a community that supports iterative reflections and discussions and continuous feedback for peers[1\0].

Our goal was to not only develop exemplary learning materials that will result in well-justified claims, but also to extend what we currently know about student learning of integrated, contextualized STEM content. In order to enhance technological literacy and to integrate math, science, and technical writing into a contemporary context, a new math-science block course, Frets, Flutes, and Physics, for freshman at Arizona State University has been developed. The inquiry-based course is in a College of Liberal Arts and Sciences (CLAS) Learning Community and consists of an 11-credit hour course to satisfy basic math, laboratory science and English requirements. The course has been developed and has been taught by an interdisciplinary team consisting of a physicist, mathematician, engineer, educator, musician, and science teacher. The context for the math, science, and technical writing was the design and building of musical instruments. Students used the engineering process to design, construct, and demonstrate instruments. Additionally, a music school faculty and music librarian arranged weekly integrated sessions demonstrating the history, culture, physical features, and musical character of a wide variety of instruments played by local professionals and graduate students. The course was assessed with respect to change in pre-post technological literacy, problem solving ability, creative thinking and STEM self-efficacy as a result of the project. The goal was to integrate the physics, mathematics, and technical writing to understand and quantitatively and qualitatively describe the sound of music as well as design and build musical instruments using the engineering design process. Initial attitude results indicated that the students have low interest in physics and math and high interest in music and took the course because of musical interests and to fulfill university core class requirements. Details of demonstrations, instruments constructed, barriers and affordances to learning, and assessment results will be shown at the conference and are exemplified by the technical literacy and problem solving and creative thinking skills acquired through the course. A learning path was developed for the course, with instructional materials to engage students in the design process, the development of mathematical and technological supports, and a plan for instructional materials that is similar to that created for Carpenter, Fennema & Franke's Cognitively Guided Instruction[11]. This initial model for learning informed the measurement and evaluation, and/or modification of measurement instruments. In effect, we integrated the development activities around the central notion of student understanding. This initial model will be improved by learning through the engineering process of iteration during classroom trials.

The course was created that uses the real-world context of music and musical instruments to connect science, technology, engineering, and mathematics to develop students' skills, abilities, and self confidence for STEM. A set of student modules and associated activities materials and equipment for learning the math and physics of musical instruments was embedded in the engineering design process as implemented by the design, construction, and measurement of performance of the instruments. A set of instructor materials for the modules and associated activities materials and equipment for learning the math and physics of musical instruments was embedded in the engineering design process as implemented by the design, construction, and measurement of performance of the instruments.

A Cross Disciplinary Team Approach

The project has had an interdisciplinary faculty team from the College of Liberal Arts and Sciences, the Ira Fulton School of Engineering, the Mary Lou Fulton College of Education and the School of Music. The role, brief description, and expected impact of each team member is given below. Robert Culbertson, Associate Professor of Physics directed the project and led the development and teaching of the physics portion of the project course. His experience in teaching and expertise in physical science was utilized in leading this project. Steve Krause, Professor in the School of Materials, led the development and teaching of course content in the areas of the engineering design process and materials and their properties in musical instruments. His expertise and experience helped math, science, and engineering design in the new course.
Michael Oehrtman, Assistant Professor of Mathematics led the development and teaching of the mathematics portion of the project. His extensive experience in effective teaching of mathematics at all levels complemented the science content, and his research in how students learn was invaluable to providing a powerful direction to the course. Dale Baker, Education Professor in Curriculum and Instruction, assisted in the assessment and evaluation of the project, a role for which she is well suited from her many years of experience in teaching and conducting research in assessment. She also provided the connection to the science teaching and learning research community. Janet Meyer Thompson, pianist and Professor of Music, identified and explored the characteristics of musical instruments from the viewpoint of a musician. Her contributions brought an authentic voice for musical instruments to the course and her organization of the weekly demonstration of a wide variety of musical instruments greatly enriched the course for all involved.

Course Content and Organization

The course was taught in a studio-style environment with strong emphasis in discovery and inquiry. Considerable class time was allotted for hands-on exploration. When relevant demonstrations were presented, students were encouraged to try the demonstrations themselves. The science content included a general description of motion (displacement, speed, accelerations) and energy. The particulate nature of matter was acknowledged in modeling of solids as three-dimensional mass-spring array and in the kinetic theory of gases. Estimation activities helped develop number sense and address students' unease with vague problems and uncertain quantities. The mathematical component of the course provided deep conceptual mathematical support for the physical systems. Emphasis was on the concept of the mathematical function, rate of change, and covariational reasoning. Real physical systems were approximated by simpler systems that can be modeled mathematically. A goal was for students to become accustomed to working with functions, variables, parameters, composition of functions, and inverse functions. Specific algebraic functions will include linear, quadratic, inverse (reciprocal), sinusoidal, and exponential. In the final several weeks of the course the students used the engineering design process to construct a simple working musical instrument. The instruments included: flutes made of PVC pipe, copper pipe or bar stock; glockenspiel-type instruments, stringed instruments; and air column instruments. Broad topic areas of mathematical and physical systems relevant to musical instruments follow:

Static elastic systems. (a) Linear relationships. Hooke's law: Students investigated the extension of a spring (proportional relationship between force and displacement) and connected this through proportional reasoning. Elastic materials: students explored the connection between the spring constant and Young's modulus. Particulate nature of matter: By modeling a solid as small masses connected by springs, students calculated the interatomic spring constant using Young's modulus and estimated atomic spacing. (Interestingly, the stiffness of the interatomic bond for typical metals is comparable to the stiffness of springs that the students use in the Hooke's law activity.) Students were pressed to distinguish proportionality from linear relationships, that is, recognize the significance of the intercept. (b) Quadratic relationships. Students investigated the energy stored in a spring and connected this to related systems in students' experiences.

Oscillating systems. Students investigated sinusoidal functions, both mathematically, using a computer to manipulate $y(x) = A \sin (Bx + C) + D$, and physically, by studying the oscillations of a hanging spring with various masses. Investigate energy (kinetic, potential, total) in oscillating spring system. (see also Appendix for example of one three-hour activity on *vibrations* from a related course). Resonance of simple mechanical systems was studied, and extensions to more complex mechanical systems as well as electrical systems were explored.

Waves. Wave speed was defined and measured using transverse wave pulses along a long spring; students distinguished between forward motion of a transverse wave pulse from transverse motion of the wave medium. Students were introduced to reflection and interference, and they made connection to standing waves. They compared and contrasted transverse and longitudinal waves in a long "slinky" spring. They explored standing waves using a vibrating spring. The students mathematically modeled wave motion with a two-dimensional sinusoidal function, constructed by students after manipulating the one-dimensional sinusoidal function previously studied. Students also discovered that their mathematical model for a vibrating spring is not unique, that is, higher frequencies (harmonics) also occurred. Connections to related topics, such as waves in fluids, solids; seismic waves was noted. Connect to two-dimensional systems (drum head) and three-dimensional systems (such as gases). Compare and contrast string model (finite tension, zero stiffness) with a solid bar (zero tension, finite stiffness) A relevant introduction to the kinetic theory of gases may be included. (see also Appendix for example of one three-hour activity on *waves* from a related course)

Musical instruments. Students explored behaviors of various physical systems that produce musical sounds. They applied physical and mathematical reasoning from the first part of the course to try to explain these behaviors. They designed a simple musical instrument, with the goal being to construct it and demonstrate it at the end of the course. They experienced the engineering design process through the iteration of a design, construction, and evaluation cycle.

Results, Discussion and Conclusions

The course was successfully offered during the Fall 2008 and 2009 terms with seven and ten students, respectively, who were fulfilling English, mathematics, and science requirements with the 11 hour course. Every week of the 15 weeks the students attended two 75-minute pre-calculus math classes, two 75-minute English classes on technical writing, two 75-minute introductory physics classes and one 3-hour physics laboratory. During laboratory the students collected and analyzed data on experiments on waves, static elastic systems, and oscillating systems using the mathematics learned in the week's mathematics course. They also built four musical instruments during the course of the semester. There was also a demonstration class for 90 minutes during which the students learned the fundamentals of music after which demonstrations on a variety of instruments from different cultures were performed. These "concerts" also formed the subject of a number of essays in the English class.

Application of the engineering design process for the design and construction of a set of wind chimes is shown in the Appendix. The example demonstrates that the students utilized the mathematics principles in the course for the design of the chimes and communicated the design quite well with the sketches shown in the student work. Overall, the integrated course greatly enriched the students understanding of the connections between math, science and the music and instruments of everyday life. The results and analysis from other assessment tools is ongoing and will be shown during the poster presentation section.

In 2009 an anonymous daily survey for the physical science course and the seminar course was administered. Students were asked to respond to a handful of questions, such as “What was the most interesting point or feature of today’s class?” “What was the least clear or least interesting point or feature of today’s class?” “What in today’s class do you think you may be able to use in the future?” and “Please give today’s class a rating from 1 to 10, with 1 for the worst class ever, and 10 for best class ever.” Students’ responses were short but information could be obtained about the general nature of each students approach and attitudes about their learning. These are summarized in Table 1.

The course will be offered a third time in Fall 2010 without English composition; the rationale behind omitting this component is to increase enrollment, after it was discovered that many potential students already had credit for English composition. The framework and assessment plan refined in 2009 will be fully in place for the 2010 cohort.

Table 1. Summary of each student's approach and attitudes about learning in PHS 110.

Student	Q1: What was the most interesting point or feature of today's class?	Q2: What was the least clear or least interesting point or feature of today's class?	Q3: What in today's class do you think you may be able to use in the future?	Q5: Please give today's class a rating from 1 to 10, with 1 for worst class ever, and 10 for best class ever.
1	Learning relationships of physical quantities; learning how things work	Understanding equations; math	Use of tools; learning how to make things	7.2 +/- 1.4
2	Learning things for exams;	Making something work	Using tools; learning facts; problem solving	7.1 +/- 1.6
3	Learning connections between math and science	(very little)	Learning about Excel; using tools; how things work	8 +/- 1.2
4	Going over problems; getting projects finished	(very little)	Learning the math; using tools	8 +/- 1.9
5	Working on projects	(very little)	How instruments work; using tools	8.2 +/- 1.1
6	Using technical software; working on projects; working with apparatus	(very little)	(very little)	7.8 +/- 1.2
7	How things work; learning how instruments work; learning to solve problems	How to do calculations; why things don't work	Learning about Excel; using tools	7 +/- 1
8	Working on projects	Trying to understand hw/exam questions	Using tools; problem solving	8.5 +/- 1.1

9	Using technical software; working on projects; working with apparatus	Math; exam/hw questions	The projects	6.2 +/- 1.3
10		New topics hard at first	The projects; learning about Excel	

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Bibliography

1. National Research Council (1999).*How People Learn.* J. Bransford, A. Brown & R. Cocking

(Eds.). Washington, DC: National Academy Press.

2. National Research Council (2001). *Knowing what students know: The science and design of educational assessment.* Pelligreno, J., Chudowsky, N. and Glaser, R. (eds.) Washington, DC: National Academy Press.

3. National Research Council (2005). *How Students Learn.* Donovan, M. & Bransford, J. (Eds.). Washington, DC: National Academy Press.

4. Aspy, D.N., Aspy, C.B. & Quimby, P.M. (1993). What doctors can teach teachers about problem based learning. *Educational Leadership*, 50, (7), 22-24.

5. Duch, B., Groh, S. & Allen, D. (2001). The Power of Problem-Based Learning: A Practical "How To" For Teaching Undergraduate Courses in Any Discipline. Sterling, VA: Stylus Publication.

6. Bandura, A. (1969). *Principles of behavior modification.* New York: Holt, Rinehart, & Winston.

7. Bandura, A. (1977). *Social learning theory.* Englewood Cliffs, NJ: Prentice-Hall.

8. Bandura, A. (1997). *Self-efficacy: The exercise of control.* New York: W.W. Freeman and Company.

10. Baker, D., Roberts, C., Krause, S. Garcia, A., Robinson Kurpius, S. Middleton, J., Evans, D., Anderson-Rowland, M., Banks, D., Gengler, C. & Yasar, S. (2003). "Designing a Graduate Education Course for Design, Engineering, and Technological Concepts for K-12 Teachers." 2003 Frontiers in Education

11. Carpenter, T. P., Fennema, E., & Franke, M. L. (1996). Cognitively Guided Instruction: A knowledge base for reform in primary mathematics instruction. *Elementary School Journal, 97*,(1), 1-20.