Physics, Physiology and Technology: Design and Testing of a High School Science Program

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Always Wear Your Helmet!
One of the main causes of accidental death in the home is a blow to the head suffered in falls. Most of these falls are from heights of no more than two meters. How can such falls generate enough force to kill?

Armed with calculators, Newton's formulas and a few assumptions, students calculate the force in this "crushing" experience. Much to their surprise, they find that the force is equivalent to that exerted by an elephant standing on the victim's head.

The activity "Always Wear Your Helmet" presents the kind of problem students solve during a typical class in the high school *Physics, Physiology and Technology (PP&T)* program now being developed by the University of Hawai'i's Curriculum Research & Development Group (CRDG). *PP&T* is being developed and tested in heterogeneous classes at CRDG's laboratory school to satisfy the national demand for standards-based science education that is accessible to all students.

PP&T involves students in studies of Newtonian physics, analog studies in physiology, and studies that apply physics and physiology principles in engineering, medicine, ergonomics, sports and dance. The program is founded on the assumption that meaningful, functional knowledge is best gained through engagement with real phenomena. *PP&T* emphasizes work in the laboratory and field. Innovative experiments use simple, easily constructed equipment assembled or made by students. The students use computers in simulation, information gathering, analysis and in reporting their progress.

BACKGROUND

Over the past 30 years we at CRDG have tested the major science programs in our laboratory school as they have appeared on the national and international scenes. In response to this research we have developed an independent design for a K–12 continuum of science, health and technology courses. As part of this continuum, we have engineered a foundational K–9 suite of three programs that are now in national and international use. These are the K–6 *Developmental Approaches in Science, Health and Technology (DASH)* program, the middle school *Foundational Approaches in Science Teaching (FAST)* program and the 9th through 12th grade or high school *Hawai'i Marine Science Study (HMSS)* program.

Still being developed are three capstone secondary programs:

- *Physics, Physiology and Technology (PP&T)*—A 10th-grade program for the study of classical physics and mechanical aspects of physiology, with technological applications in ergonomics, medicine, sports and dance.

- *Chemistry, Cells and Technology (CC&T)*— An 11th-grade program for the study of basic chemistry through biochemical, organic and inorganic examples with applications to cell physiology, molecular biology, chemical technology, bioengineering, medicine and environmental stewardship. This program is currently being conceptualized.

- *Mind, Matter and Technology (MM&T)*— A 12th-grade program for the study of the evolution of the nervous system, artificial intelligence, relativity, modern particle physics and quantum mechanics, emphasizing information in systems, medicine and the epistemological and social implications of science and technology. This program is also currently being conceptualized.

DESIGN ASSUMPTIONS

PP&T is being designed, developed, and organized around a series of assumptions held in common with other CRDG science, health and technology programs.

- All students enrolled in public schools must be able to use the program successfully .

- Pedagogy should consider the constructivist psychology of child development to provide a research basis for selecting ways to engage students in knowledge generation.

- Sequencing of scientific and technological content and skills should be guided by recapitulation of historical pathways of their knowledge generation.

- Materials and teaching strategies should be designed for use in heterogeneous classes.
- Roles of teachers and students in the classroom should reflect the roles of professionals working in the sciences and technologies.
- Philosophical content should include reflection on epistemology and the social impact of material and intellectual progress achieved by science and technology, including the concerns that this progress has generated.
- Individual programs should integrate into a K–12 multidisciplinary continuum of science and technology study responsive to the developmental needs of children.

Constructivist Psychology

Guiding our development of *PP&T* is the constructivist assertion that knowledge is built by the individual out of personal experience. The intentional shaping of the experience of others constitutes teaching. Teaching allows the building of the common bodies of knowledge that characterize an educated person. Because knowledge of authentic science and technology is considered to be a social imperative, students must have an experience in what scientists and technologists do. This translates into learning environments where classrooms are laboratories in which teachers create problems that are true to the history of science and technology and students construct their own problem solutions, test and discuss them and reshape them in the light of experiment and colleague response. In this building of knowledge, new experience is interpreted and made functional as it is connected with past experience (Matthews, 1994).

PP&T seeks to provide learning experiences for students in their mid-teens who come to science studies with diverse backgrounds and wide differences in their cognitive achievement. Constructivists observe that in passing from childhood to adulthood, individuals gain access to ever more powerful cognitive levels of information processing, the highest of which is formal or abstract thinking. Though a considerable percentage of students begin abstract or symbolic thinking in their early teens, many high-school students still need or prefer knowledge-making experiences that involve manipulation of concrete things that are explored in social surroundings.

In *PP&T*, experience in the laboratory and field involves students in real phenomena that they create through personal manipulation and then observe. Starting with tangible things, the students move toward abstract generalization and mathematical expression of concepts.

PP&T also uses the dynamics of the classroom community to help in the transition to formal thinking. In this social environment personally constructed ideas are solidified or modified through interaction with classmates and teachers. The student who is not yet using abstract thinking can observe operating models of such thinking in others and through interpersonal interaction can begin to practice emulation.

Recapitulation

Piaget and other researchers indicate that the child's original construction of the concepts of science and their later normalization of these concepts to fit accepted standards of current knowledge follow a common pattern of development that roughly recapitulates the history of scientific knowledge generation (Piaget, 1973). The historic path of knowledge making must be experienced and walked anew as the infant evolves into an adult. Accepting this idea, we at CRDG have used a historical perspective of science and technology as a guide to organize the content and pedagogy of *PP&T*.

This has resulted in the organization of *PP&T* around Newtonian-era physics and the parallel physiology and technology that developed along with this body of physics. Working on questions similar to those asked by early investigators allows students to construct anew the basic concepts and techniques that are the fundamentals of these sciences today.

Heterogeneous Classes

PP&T encourages heterogeneous class organization for several philosophical, psychological and sociological reasons:

- Constructivist philosophy suggests that learning, though personal, is driven and structured by corrective social forces (Vygotsky, 1978).
- Cooperative learning literature brims with evidence supporting the enhanced effectiveness of learning in a helping classroom community (Johnson et al, 1986).
- Multiple intelligence literature speaks of the distribution of talents in populations. Students have different talents, and these are productively employed in the heterogeneous class (Gardner, 1983).
- Heterogeneous classes build an egalitarian sense of social responsibility and good citizenship.

Staff working on *PP&T* recognize that the major barrier to student success in science courses has traditionally been the requirement of proficiency in reading, writing and mathematics as evidenced by individually produced products. While valuing traditional skills, *PP&T* provides alternative routes to understanding by drawing on the students' multiple intelligences. The abilities to collectively talk about, kinesthetically manipulate and spatially visualize objects have traditionally received little emphasis in science teaching, though they are greatly prized in sciences and technologies.

PP&T marshals these abilities by having students work collaboratively in groups where each student contributes of their strengths. Because laboratory and field work provide a major part of the *PP&T* experience spatial and manipulator skills are much used and valued. By calling upon a fuller range of intelligences, all students are provided additional routes to understanding. Tools specially developed to aid conceptualization through spatial and kinesthetic manipulation include computer graphing, report building and simulation programs.

Connections

Constructivists recognize that isolated, unconnected facts and concepts are quickly lost from memory. Connection between previous and ongoing experiences is essential to functional learning. *PP&T uses* a series of strategies to help students recognize connections. The simplest is to ask "What are other examples of this?" The most comprehensive is to have students make connections through group and independent projects that enfold old and new ideas. This is most often done in a technology context of invention.

In American science education, a major problem has been the absence of developmental continuity and connection in content. In its most fragmented presentation, which is exemplified by the general science textbook approach, science is treated as a miscellaneous collection of concepts. In its most connected and integrated presentation, science is treated as a collection of topics of the disciplinary areas within a broad field such as biology, chemistry or physics. With either of these approaches, few students ever get a sense of science as a grand and growing enterprise of linked theories and practices. Each course is seen as an independent intellectual exercise, a set of ideas never woven into the greater fabric of science and technology.

PP&T presents the historical interplay of physics and physiology and the technologies that have drawn upon explanations and motivated inquiry of these fields. The work of Newton and his contemporaries provides physics investigations that interface with investigations of 18th and 19th century physiologists. *PP&T* investigations stress the shared basic concepts of both disciplinary fields and explore their use in associated technologies. This form of integration has several advantages:

- It engages students in constructing their knowledge of physics in a physics environment.
- It engages students in constructing their knowledge of physiology in a physiological environment while using knowledge already generated in physics to shape explanations.
- It engages students in the construction of knowledge of technologies in a technological environment out of knowledge already generated or yet to be generated in physics and physiology.
- It lends itself to philosophic reflection on scientific history, epistemology and the social impact of science and technology.

PHYSICS, PHYSIOLOGY AND TECHNOLOGY PROGRAM

PP&T has five areas of study. These are physics, physiology, engineering technology, biological technology and philosophy and history. As shown in Table 1, each area has several components.

Table 1
Content of *Physics, Physiology and Technology (PP&T)*

Area	Components
Physics	Statics, Dynamics, Hydraulics, Pneumatics, Heat, Sound, Light, Electricity
Engineering Technology	Static structures, Mechanical, Hydraulic and Pneumatic Machines; Optical, Sound, and Electrical Devices and Automation
Physiology	Cell Structure and Physiology; Skeletal and Muscle Physiology; Cardiac, Vasomotor, Gastrointestinal, Respiratory and Renal Physiology; Sensory Physiology and Nerve physiology
Biological Technology	Exercise, Sports, Dance, Medicine and Ergonomics
Philosophy & History	History of Newtonian Physics, 17th and 18th Century Physiology, Epistemology and Social Impact

Historically, physiologists have drawn upon the work of physics in their explanation of the function of the body and its organs. Technologists on the other hand, have only in relatively recent times used the work of science as a major source of ideas. Many technological devices were invented and used thousands of years before their operations were explained by science. People were using levers to pry and throw stones, pumps to lift water, lenses to magnify objects long before the principles on which these devices operate were hypothesized. Often technological products inspired scientific inquiry. In *PP&T* technological activities are introduced when needed. These activities may act to define questions and thus initiate investigation of principles or they may act to reinforce and connect principles already developed to the practical domains of products and services that the students know. Philosophical and historical content is interspersed in backgrounds and reflective problems.

Analogous Topics

The relationship of physics, physiology and technology can better be seen in a sample of analogous topics shown in Table 2. Each of the components above is made up of several topics that in turn are studied in activities.

Table 2
Sample analogous topics in *Physics, Physiology and Technology (PP&T)*

Physics	Physiology	Technology
• Force, velocity, acceleration, work power, levers	• Muscle action, body movements	• Compound machines Sports, Dance
• Statics	• Skeletons, upright posture	• Stress in buildings, bridges and other structures
• Pressure in its several forms	• Lungs, hydrostatic skeletons, blood and osmotic pressure	• Hydraulic and Pneumatic machines
• Fluid flow, resistance in closed systems	• Circulatory system	• Pumps, municipal water systems
• Longitudinal waves in air, water and solids	• Ears and hearing	• Music, musical instruments
• Heat energy: generation, transmission, dissipation	• Dissipation of heat in biological systems, homeostatic temperature	• Heat engines, heat exchangers, refrigeration
• Waves and the electromagnetic spectrum	• Light reception and function of the eye	• Electromagnetic energy in medicine and industry
• Light transmission and refraction	• Structure of the eye	• Optical instruments
• Electricity and its transmission	• Nervous system	• Electrical devices

Examples of *PP&T* Activities

"Always Wear a Helmet" described earlier is representative of a summarizing physics activity introduced after students have studied force, velocity and acceleration. Students are presented with a problem and a brief discussion of possible attack. The students are left to come up with a solution on their own with the teacher being available for consultation at all times. They must select principles from previous work that apply to answering the question posed.

"Rube Goldberg Day" is representative of an engineering technology project. In the activity, students are given the problem of making as complicated a machine as they can to do something that is quite simple? One task is to build a system that will flatten a Styrofoam cup. The flatter the better.

The following vignette is taken from a student's report on the project. The room is full of pulleys, inclined planes, screw jacks, wedges, levers and wheels and axles. Students wearing goggles are wielding hammers and saws, masking tape, string and glue. Excitement and nervousness are in the air as they await the unveiling of their compound machines. The objective: use as many different types of simple machines in sequence as possible to flatten a Styrofoam cup. Think it sounds easy? You try getting a lever to catapult a mass to land on a ramp and roll down onto a pair of scissors that cut a string, releasing a screw jack that swings a bat towards a Styrofoam cup. And, by the way, remember, how flat the cup is counts.

"Attack of the 30-Foot Woman" is a typical summarizing physiology activity. Students are confronted with the question, "Could a 30-foot human be fully functional on earth?" The students have as a background work on forces, machines and statics as well as the function of the human skeleton and muscles, static and dynamic bone stress, changes in volume as a function of size and pressures in the body. All of these come into play as students hypothesize and calculate human height limits which, incidentally, seem to exclude the possibility of there being a functional, unsupported, 30 foot human earthling who has our present body structure.

What Students Do

PP&T students spend between 50 percent and 75 percent of class time in the laboratory and the field. The remaining time is spent digesting and organizing laboratory and field notes and computer-recorded results as well as working with integrating, extending and routinizing problems.

Laboratory Equipment and Computers

The *PP&T* classroom is an active research laboratory. Often several related student investigations occur simultaneously. This contributes economy in the purchasing of specialized equipment. By rotating students through three experiments, one-third as much equipment is needed. Further economy is achieved by having students construct much of the specialized equipment from standard laboratory apparatus and lumberyard and hardware store items. Saws, hammers and drills must be added to the normal classroom equipment kit.

Hawai'i and many other states are moving to make computers available to all secondary science classrooms. *PP&T* takes advantage of this trend by producing programs for use with simulations, data collection, project reporting, data analysis and laboratory sensors.

Student Evaluation

We at CRDG have studied student evaluation extensively and have found that traditional paper-and-pencil tests alone give a limited view of the learning of students. Because all students are to be included in the instructional scheme of *PP&T*, it follows that a multiplicity of indicators must be called upon if a fair evaluation of student learning is to be given. In the light of this, the project is producing an evaluation guide that keys a concept and skill inventory to a wide variety of evidences of achievement found in the program, including laboratory skill assessments and invention and discovery inventories as well as project-generated paper-and-pencil examinations. The students are also involved in self-assessment. *PP&T* students are experienced in creating electronic portfolios and working with computer programs developed at CRDG, including an automatic interviewer, a portfolio builder and a class data collection system (Speitel, 1995; 1996; 1996).

Program Development

The *PP&T* staff includes seasoned designers, teacher-researchers and content experts. Materials are receiving their first trials in CRDG's laboratory school, where classes have a heterogeneous mix of students who have been selected to provide an intellectual, ethnic and socioeconomic representation of the state's public school population. Development teams include Hawai'i Department of Education teacher-researchers who work as colleagues with CRDG staff. These teachers help in formulating activities, pilot test the materials in their classrooms and provide crucial feedback for refinement. In the near future mainland teachers will trial-test the materials in diverse school settings.

Dissemination

It has been the experience of CRDG that work done in Hawai'i will readily transfer to U.S. Mainland and international schools. Curricular materials produced by CRDG are published by CRDG. Currently CRDG is working with a consortium of mainland universities that cooperate in training teachers, provide follow-up services, help in localization and cooperate in evaluation of its programs. This system will be used with *PP&T*.

Training

CRDG science programs are made available only to teachers who have been trained in their use. Teacher institutes are usually of two-weeks' duration, eight hours per day. Follow-up activities such as video conferencing, on-site visits and refresher workshops are made available. Because of the nature of the program's teaching strategies, content and equipment handling, the same procedure will be followed for *PP&T*.

Conclusion

A concluding consideration needs to be mentioned. Though *PP&T* presents a new organization of the curriculum and thereby challenges traditional school course sequence, it captures the intent of NSTA's Scope and Sequence proposal (Aldridge, 1992) that calls for parallel studies of different disciplinary areas. It satisfies the standards literature calling for the incorporation of math and technology in the science curriculum (NRC, 1996), and it meets the call for science for all (AAAS, 1989). Further working in its favor, *PP&T* is coming onto the curriculum scene at a time of shortage of physics teachers, at a time when a common solution to the shortage is to put biology teachers in physics classrooms. *PP&T*'s cross-disciplinary nature gives special support to these teachers, for they find its content closely mirrors their academic preparation. But most important, by making physics personally relevant to students through its applications in physiology and technology, *PP&T* promises to become an exciting and inclusive program for all American high school youth in the century to come.

Another Day in the Classroom (From a teacher's journal) *Just what do students in Physics, Physiology & Technology do in the course of the day? They build things; they break things; they make discoveries and calculations; they collect data and generate hypotheses; they learn a lot about the world and themselves and they have fun doing it.*

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The annual *Rube Goldberg* competition allows for creative uses of technology

Team work is important in the collection and analysis of data

Another lab group competes for the *Rube Goldberg* title

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