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From the Editor

The Deer or the Driver?

The tragedy of September Eleventh is over a year behind us. Little did I know in the days following that event that there would be a connection to the JTE. Email messages arrived from around the world, expressing concern about what had happened. Most of the messages came from people with whom I have worked in my editorial role. It occurred to me once again how global our profession has become over the past couple of decades as a result of the work of individuals and professional organizations, as well as the technological systems of email and the Internet.

Though I have no cause-effect evidence of a connection to the catastrophe, it seems more than just coincidental that the JTE did not receive even one manuscript for nearly five months following the event. This resulted in one of the lowest years ever in terms of manuscripts submitted. Now, fortunately, the manuscript submission numbers for the year 2002 appear to be approaching the norm.

The terrorist attacks exacerbated a declining economy. Like the chain reaction of dominoes falling against each other, a number of states in the US are encountering severe shortfalls in tax revenue. These shortfalls are then reflected in budget reductions for universities. As this issue goes to press, the State of Virginia is on the verge of announcing how it will deal with a budget deficit that exceeds 1.5 billion dollars. This is on top of a severe budget cut last spring. Since personnel costs typically represent 85% or more of the budgets of most educational institutions, revenue shortfalls take their toll on faculty positions. Vacancies go unfilled and early retirement incentives are initiated. Similar economic woes are spreading around the globe.

Changes in the distribution of resources result in changes in how people and organizations go about their business. In general, technology education in the secondary schools has been quite dynamic in recent years, experiencing growth, a new focus, and renewed vigor. Federal support for some technology education programs has no doubt had a positive influence in this regard. Development at the elementary level has been phenomenal, though still rather regionalized. At the teacher education level in the US, though, there has been a sizable net loss over the past 20-25 years in the number of faculty involved in the preparation of technology education teachers.

The most significant change at the teacher education level has been in land grant, research universities. In the past, not only were these universities major producers of teachers at the undergraduate level, they were also the grantors of most of the graduate degrees in the field, including virtually all of the doctorates. Moreover, faculty at these universities did most of the research and development work. Now, the vast majority of technology education teachers are prepared in regional universities and nearly all of these institutions offer graduate degrees as well. Several of these institutions have had a phenomenal growth in the number of teachers they prepare each year and are thriving, a significant positive indicator. On the other hand, few institutions remain that offer a doctoral degree with a concentration in technology education.

In the past, those aspiring to become technology teacher educators had two, rather clear-cut options. One was to work primarily in research and scholarship in a large research-oriented university. The other was to emphasize teaching at a regional college or university. Now, there is mounting pressure at virtually every higher education institution for faculty members to procure funding, do research, and publish the results. State support for higher education has eroded significantly over the years, causing colleges and universities to rely increasingly upon overhead monies generated through grants.

Role expectations in higher education have changed dramatically as well. In years gone by, a person could be highly recognized as a professor in many universities by being a good teacher and providing service to one's profession. Especially in those universities aspiring to establish or maintain a national ranking for their research prowess, empirical research and its publication is now the expectation, *sine qua non*. Though teaching and service are valued, superior contributions in those areas alone will no longer assure continued employment as they have in the past, even at smaller, regional institutions.

Not long ago, the typical model for curriculum development in technology education involved teacher educators leading the effort, facilitated by state departments of education. As large amounts of federal money began flowing to state governments in the 1970s, some state departments of education began to provide the leadership for curriculum development. Teacher educators facilitated their efforts by delivering inservice education, effectively reversing the respective roles. In recent times, the leadership for curriculum development has begun to shift once again, this time to ad hoc groups and professional organizations, both of which are eligible recipients of grant dollars. The funding of the International Technology Education Association by NASA and the National Science Foundation to develop standards for the field is an example of this contemporary model. Even more exemplary of this changing approach is ITEA's Center to Advance the Teaching of Technology and Science (CATTS). This Center (see http://www.iteawww.org) has four goals: development of standards-based curricula, teacher enhancement, research concerning teaching and learning, and curriculum implementation and diffusion. The overlap between the goals of the Center and the goals of institutions of higher education are obvious.

The traditional curriculum development model was bound to change if for no other reason than the fact that there were not enough horses among the teacher educators to do the work. Fully fifteen years went by from the time the field redirected itself toward technology education before a reasonably clear vision began to emerge about what technology education should be. The field has desperately needed some curricular guidelines to move ahead.

Over the past year or so I have heard increasing criticism leveled at teacher educators for not contributing to the development of the profession, in comparison to their predecessors. This allegation is absolutely true when looking at teacher educators as a group. However, to suggest that the teacher educators as individuals are not working as hard as their predecessors is at once absurd and naïve. The same work simply cannot be done with only a small fraction of the people that once worked toward the endeavor. What is more, active or former teacher educators are playing a significant role in virtually every curriculum project and standards-based endeavor in the field.

The act of singling out teacher educators as a group may, in itself, reflect an outdated paradigm about how work should be done in our profession these days, a paradigm akin to the division of labor notion that started well over a century ago. The old idea of teachers doing the teaching, teacher educators doing research and curriculum development, and supervisors monitoring and facilitating the process needs to be displaced. We all have responsibility for the entire effort. We all need to use the talents that we have to contribute to the good of the whole. In other words, we need to unify the constituencies in our profession and expand the participation and role of each member. The members of our profession have increased their level of capability to participate in it through higher levels of educational attainment, professional development, organizational participation, and increased responsibility.

The interest in technological literacy is expanding at a phenomenal rate, both inside our field and out. Change is occurring at every avenue and new alliances are forming at an unparalleled rate. In the area of curriculum development, for example, a new program called Project Lead the Way (see http://www.pltw.org/) seemed to spring into the forefront of our profession, like a deer at night appears out of nowhere into the headlights of our automobile. The deer is stunned motionless by the bright lights and must gain its wits before it is able to make a decision about what action to take next. The driver is equally surprised, slamming on the brakes and trying to decide whether to maintain a straight course or veer off to the side to avoid hitting the deer. Are we the deer or the driver?

JEL

Credit

I am fortunate to have wonderful colleagues with whom to work, namely Allen Bame, Sharon Brusic and Mark Sanders. From our discussions come most of my thoughts and ideas about our profession. Though the context was different, the “deer in the headlights” analogy came from a conversation with Mark.

Articles

Defining and Measuring Technical Thinking: Students' Technical Abilities in Finnish Comprehensive Schools

Ossi Autio and Ron Hansen

The terms "technical" and "technology" are widely used by educators, workplace practitioners, and the general public. Seldom, however, is there a written explanation of a technologist's or technician's attributes (Hansen, 1994; Ropohl, 1997). What do technicians know and do? Also absent from public consciousness is a sense of what constitutes the design or problem-solving process which precedes any technological act. By comparison, media depictions of technology as computers, electronics, and tools are widespread and the public appetite for these depictions is extensive. In teacher education and in schooling itself the subject through which technical skills and knowledge are imparted suffers from confusion about definition as well. What is technical thinking? What is technical aptitude? Why is it that technology teachers can recognize this ability when it is observed in students but they, and educators generally, have difficulty documenting the essence of it in writing?

To expose what it means to be a technologist, the investigators in this research project examine what students in Finland's schools learn in their study and practice of technology. Why, you might ask, would the authors attempt to better understand what it means to have a technical orientation or technical ability by studying school children, in this case Finnish children? The answer has two parts. First, from a research perspective, children's responses to adult inquiries are often more informative and authentic than those of adults. Secondly, teachers of technology have had to think about their field, especially how to teach it. In doing so, they have to know about the substance of their subject. By comparison, practicing technicians and technologists may not have been required to think through what they know and do, much less express it.

The case of Finland's children and schools is especially timely. This country of five million people has a reputation for cherishing inventiveness and aesthetics. The essence of the creative and rational process of technology and design in Finland is found in the connection between nature and people. Our

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instincts as human beings to observe, appreciate, and respect/disrespect the patterns/cycles of the natural environment is a particularly important issue in Finland. The eye of the trained and untrained observer absorbs many facets of the physical and manufactured worlds. The combination of these activities (to see, touch, think, and do) is called "technology." It is, itself, the inherent capacity of the technologist. The degree to which students experiment with regard to the physical world is the degree to which each is a prospective technologist. In Finland the connection between technology and culture is a deliberate part of the school curriculum.

The Finnish Context

Technology as a school subject in Finnish schools has a long and rich history dating back to the 1800s when Uno Cygnaeus defined "sloyd" (Kantola, Nikkanen, Kari, & Kananoja,1999). It has evolved and is still evolving in such a way that examination of its essential elements is particularly informative. In particular, the attention to technical thinking which emerges from this history and which is the focus of attention in this study, informs readers about a host of important issues. Policy regarding the importance and place of technological education in schools, how best to recruit and prepare technology teachers, and what to teach students in the school curriculum, head the list of issues that are associated with understanding "technical thinking."

Finland's tradition in craft education is unique. For years students have engaged themselves in creative and reproductive handwork using a variety of craft and machine tools. In the early years of the last century workshop learning focused on reproduction handwork as a pedagogical strategy for developing student insight into the technological world. More recently, the curriculum has included creative handwork, textbook learning, and innovative technology (see Figure 1). The curriculum was and is geared mainly toward the development of starting-level technical thinking skills. For boys this involved crafts handiwork; for girls, textiles handiwork. In 1994 the new Finnish curriculum (National Board of Education, 1994) specified that technical craft and textile craft should be combined into one subject, taught to both boys and girls over their entire comprehensive school lives. Craft learning was designed as a comprehensive curriculum to develop psychomotor skills, "technical thinking" (knowledge), and work ethic.

"The student learns to appreciate work, to master the lifespan of the product, and to adopt the principle of sustainable development by using different planning and problem-solving methods. During the production process both a student and a teacher are continuously considering environmental, cultural, and nature values" (National Board of Education, 1994, p. 115). The value of craft teaching is described in the national curriculum as the appreciation of work in respect to ethics, ecology, aesthetics and economy, safe working habits, responsibility, consideration for others, and the all-round development of the student.

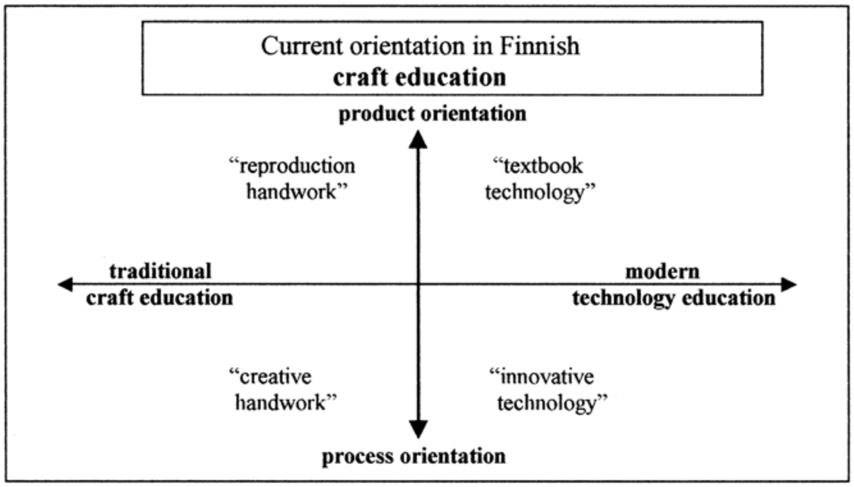


Figure 1. Current orientation in Finnish craft education (Autio, 1997, p. 32)

The Finnish national curriculum of 1994 requires that students learn to apply theoretical information to practical work. "In planning, making, and choosing the craft products, the student learns to apply theoretical information to practical work. The aim of the subject is to live through the work process where, between the start of an idea and reaching the final result, there is growth in creativity, thinking, and the development of self-esteem" (p. 113). The aim is to have students acquire the essential skills needed to manage their everyday lives. Learning, in its pedagogical sense, is experiential. The study of craft is, above all, practical rather than academic. Outcomes from learning include individual responsibility, initiative, creativity, perseverance, and a positive picture of oneself. Self-esteem, the report suggests, is built on practical rather than academic achievement.

The post 1994 curriculum proposes new approaches to students' all-round development. Technology education as a term is seldom mentioned in government documents; however, it's shadow, as cast by a growing number of middle school level technology education curricula in other countries, is evident. The fact that technology in Finland continues to be taught using formal workshop methods, with less emphasis on computer simulations, may be significant. Finland is often mentioned as a country where innovative technology, e.g., cell phone products, is prominent, yet that reputation appears to be attributable, in part, to a traditional curriculum unlike that being espoused in many contemporary school systems around the world. Finland may be the only country in the world that has a compulsory stand-alone technological arts subject in its primary schools, and a system of teacher preparation for that subject. Finnish comprehensive schools do not have a subject equivalent to technology education in the United States. Technology education, to the extent that it has evolved in Finland, has been taught as a part of the instruction in science and craft education (see Figure 2). Only in 1994 was technological literacy introduced as a national educational objective. This study addresses the Finnish "case" by investigating how students become technical thinkers, through traditional and contemporary craft curricula with a technological literacy emphasis.

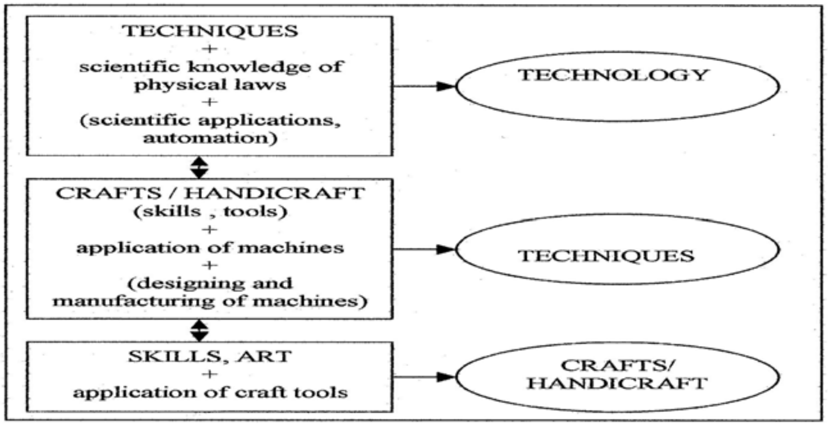


Figure 2. Conceptual foundation of technology (Parikka, 1998, p. 40)

Evidence (Alamaki, 1999) suggests that instructional goals and methods in Finnish schools are changing: Reproduction handwork and design are being merged with general knowledge of craft tools and technological literacy. Historically, technological education in Finland fulfilled the requirements of an agricultural society. The emphasis was on tool and machine use. Today, like many developed countries, it seeks to meet the requirements of a post-industrial society, complete with scientific knowledge of physical laws and automation. Parikka's conception (Figure 2) of the relation between technology, techniques, and crafts is helpful in describing one vision for something other than technological arts in Finland's schools.

In spite of Parikka's proposed reconceptualization, Alamaki points out that woodwork is still the most popular technological activity in Finnish primary schools. "It is clearly more popular than other activities such as plastic work, metal work, service and repair of technical equipment and construction of electronic equipment. Least popular are construction kits, internal combustion engines, and familiarity with technological equipment" (p. 143-144). Computers are not commonly used in these programs, although usage is expected to increase in the near future. Could the fact that Finland reveres a practical pedagogical tradition in the teaching of technology be related to this country's apparent success in both the design arts and in the new technology fields?

The changes that have occurred in Finnish classrooms and workshops are encouraging. Much work is being done to introduce the principles of creative problem solving. However, the search for clarity, confirmation, and definition of technology education is on-going. A formal definition of "technology education," for example, has not been articulated. More important, an understanding of the elusive aptitude known as "technical thinking" and its roots remain a source of debate. The fundamental issues are as follows: Can "technical thinking" be defined and measured? What is the relation between an experiential pedagogy and developing the ability to think technically?

The Research Design

Defining and measuring technical thinking as a construct was achieved by extending the work of Dyrenfurth (1990) and Layton (1994). They identified three components that correspond with what the authors considered to be the dimensions of technical thinking. The first is technological knowledge. Citizens in a democratic society, according to Dyrenfurth, know something about technological concepts, principles, and connections, as well as the nature and history of technology. This kind of "knowing" is often referred to in the educational sciences literature as the cognitive domain. The second dimension of technical thinking is skill or "competence." Technical and technological skills are part of most human activity and are essential for the survival of humankind. These skills are often labelled by psychologists as "psychomotor" skills and are an important component of technical thinking. These skills involve tactile or kinaesthetic ability and practical intelligence. The third dimension is technological will or "being active and enterprising." Technology is determined and guided by human emotions, motivations, values, and personal qualities. Thus the development of technology in society is dependent on citizens´ technological will to participate in, and have an impact on, technological decisions (individual and/or societal). This is the affective or emotional aspect of technical thinking. Technical thinking, in short, involves a balance of knowledge, competence, and emotional engagement. In its fullest sense it is the act of using human ingenuity or, being ingenious.

After extensive pilot work, three test instruments were developed, one to measure each of a) competence/motor skills, b) technological knowledge, and c) emotional engagement. The test of motor skills is called X-boxes and was based on the theory of Powell, Katzko & Royce (1978, p. 194) and Fleishman & Hempel (1954, p. 248) (see Figure 3). In this test all the elements of bodily orchestration, precision, vocalization, motor reactivity and dynamism are involved. The reliability of this test was 0.819 as measured with the Cronbach Alpha.

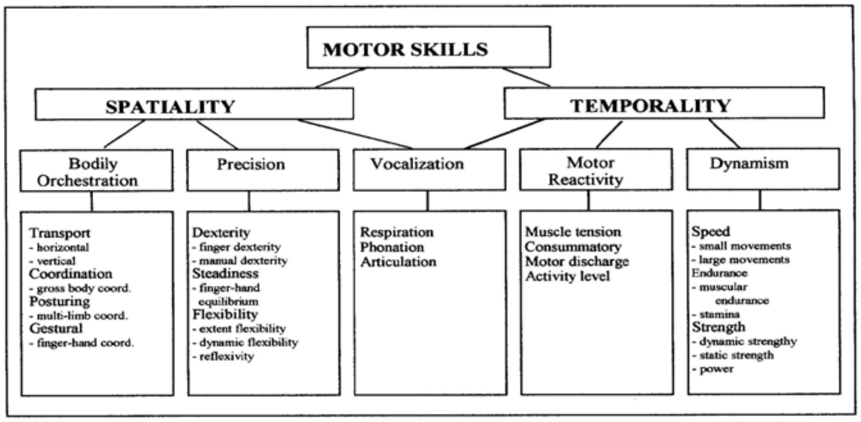
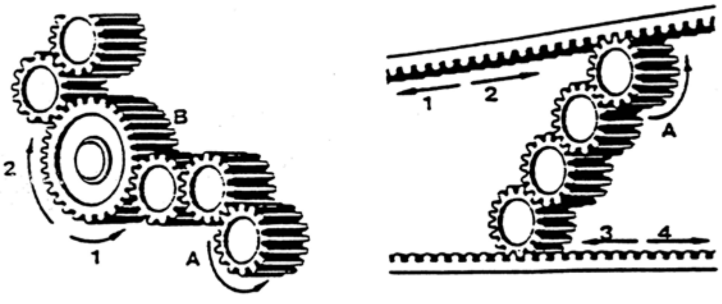


Figure 3. The hierarchical structure of motor skills (Powell, Katzko & Royce, 1978, p. 194)

To detect and measure the cognitive dimension of technical thinking, the instrument used was a test of "technical knowledge." It consisted of three different parts with twenty-eight questions. The questions deal mainly with physical laws, often observed in simple machines. Other aspects of technical knowledge are also involved, e.g., tool design and application. The reliability of the test, measured with the Cronbach Alpha, was 0.881. Figure 4 provides some example questions.



If cogwheel A rotates to the direction of the arrow, in what direction does cogwheel B rotate?

a) direction 1
b) direction 2
c) cogwheels can not rotate

Cogwheel A turns to the direction of the arrow. In what direction do the coglevers move?

a) direction 1 and 3
b) direction 2 and 4
c) direction 1 and 4
d) coglevers can not move

Figure 4. Example technical thinking questions

Emotional engagement was measured with a questionnaire based on the PATT (Pupils Attitudes Towards Technology) material designed and tested by Raat & de Vries (1986) and van de Velde (1992). The designers tested the questionnaire on several occasions. From their studies six factors associated with technical attitudes were found: interest in technology, favourite role models, understanding that consequences are a reality, some aspects of project work are difficult, attitudes towards school and technology, and career aspirations. These factors were used to establish the final test B, a questionnaire with fourteen Likert scale statements. Although attitudes are not best measured with paper and pencil tests, the test worked quite well, especially in detecting differences between the control and experimental groups. Test reliability was 0.853.

Evidence that the new curriculum in Finland either fostered or discouraged technical thinking in students would require that these three instruments be applied in the classroom. Each instrument was used three times over four years (pre-measurement, intermediate, and final measurement). Data were collected on 267 students in grades five to nine. The experimental group consisted of four classes from university training schools in Helsinki. Male and female students were given a new curriculum that combined technical and textile craft projects at the grades five to seven level (two classes), and an additional technology component at the grades seven to nine level (two classes). This curriculum included the teaching of problem solving with computer animations, as well as "hands-on" projects. The control group included classes from four local schools in Helsinki. Each class used the traditional crafts curriculum and pedagogical methods. Boys worked on technical craft projects, girls on textile craft. These four classes worked on projects that included wood and metal work, with some electronics. The grades seven to nine boys received a slightly greater emphasis on computers and electronics. The textile craft curriculum included mostly handwork and machine sewing. The classes were organized according to grade level and craft subject. In textile craft ninety-nine percent of the students were girls and in technical craft/technology ninety-five percent were boys.

Technical achievement was assessed using three tests that correspond to the conceptualization of technological thinking described earlier: 1) psychomotor domain (human competence/motor skills), 2) cognitive domain (technological knowledge), and 3) affective domain (emotional engagement). The research design is described in Figure 5.

From this research we wanted to explore, in a preliminary way, whether or not a curriculum which combines or retains traditional textile and technical crafts, or new technology education, would enhance technical thinking. Our hypotheses, while not formally stated, were that technical thinking as a construct could be defined and measured, and technical thinking could be linked more directly to technology education than to crafts education. The important research questions were: a) could/can student achievement in technological knowledge, competence, and emotional engagement be identified and measured? b) could/can technical thinking ability in students be attributed to different treatments, i.e., traditional curriculum versus technology enhanced combined crafts curriculum? c) are there any differences in development between boys and girls as a result of these different treatments? d) is individual student technical ability evenly distributed across motor skills, technological knowledge, and emotional engagement? and, e) what impact, if any, can be attributed to the pedagogy practiced in traditional craft education compared to the emerging pedagogy practiced in more contemporary classrooms/workshops?

Groups	**Pre-Measurement**	**Treatment**	**Intermediate Measurement**	**Treatment**	**Final Measurement**
Experimental group Combined craft (*n*=116)	O_1	X	O_2	X	O_3
Control group (*n*=151) Technical & textile craft	O_1	X	O_2	X	O_3
Test Instruments/Areas	-motor skills -technical knowledge -attitudes/ emotions	-combined technical/ textile	-motor skills -technical knowledge -attitudes/ emotions	-combined -technical/ textile	-motor skills -technical knowledge -attitudes/ emotions

Figure 5. The research design

The Results

The results show that in the psychomotor area (motor competence), student technical abilities improve quite a lot even with a small amount of practice. Significant improvement (p < 0.001) was found in both control (textile and

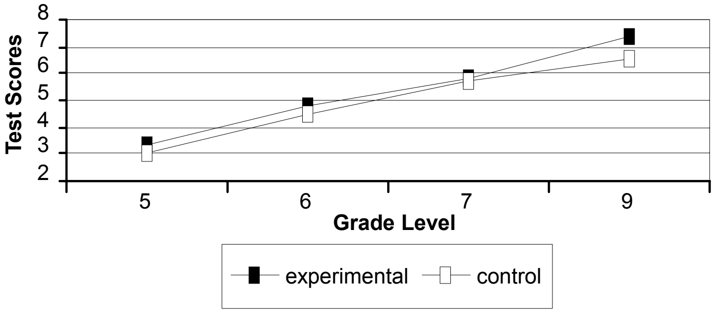


Figure 6. Development of psychomotor skills ($n = 267$, $p < 0.001$)

technical craft) and experimental groups (combined craft). Students excel at psychomotor activities in craft related projects. Figure 6 shows how psychomotor development increases from one grade level to the next.

According to the data there were no significant differences between the motor competencies of boys and girls, although, in the final measurement (grade nine), a significant difference was found ($p = 0.01$, see Table 1). Differences from one grade level to the other were also significant ($p < 0.001$), i.e., between children in grade five versus those in grades seven, and between grades seven and nine. Interestingly the experimental group achieved better results in every measurement. When technical and textile craft are combined, competence and motor skills receive more emphasis than technological knowledge. The wider range of experiences with different materials and projects may be an important factor.

Table 1
Average Scores in Motor Skills

Group	Pre-Measurement	Intermediate Measurement	Final Measurement
Experiment group (*n*=116)	4.17	5.58	6.68
Control group (*n*=151)	3.80	5.00	6.29
Boys (*n*=161)	4.05	5.26	6.58
Girls (*n*=106)	3.83	5.23	6.28

In the cognitive (technological knowledge) domain, achievement is similar between the control and experimental groups (see Figure 7). Even when students reach the grade seven to nine level their technological knowledge increases at a steady rate.

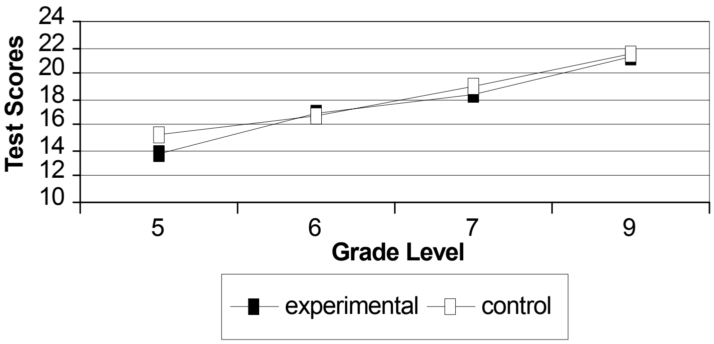


Figure 7. Development of technological knowledge (n = 267 $p < 0.001$)

According to the data (Table 2) there are significant statistical differences in the cognitive domain between boys and girls ($p < 0.001$). This finding corroborates results in other studies that look at cognitive development (Autio, 1997; Halperin, 1992; Kalichman, 1989). By contrast, there were no statistical differences between the control and experimental groups on test scores. This is due to the fact that in the cognitive area, the older girls had much better results in the combined craft than in textile craft. It seems that the girls in combined craft benefit from technical craft lessons even though some project work was not technological. Among younger boys the result was the opposite. Boys in the control group (technical craft) scored better than boys in the combined craft (experimental group).

Table 2
Average Scores in Technological Knowledge

Experiment/Control Group	Pre-Measurement	Intermediate Measurement	Final Measurement
Experiment group (*n*=116)	16.16	17.33	20.24
Control group (*n*=151)	16.15	17.53	20.61
Boys (*n*=161)	17.38	18.87	21.72
Girls (*n*=106)	14.29	15.27	18.52

In the affective domain (emotional engagement) change over time was not distinguishable. Only in the higher grades, when students are able to concentrate more seriously on activities in which they were genuinely interested, do attitudes towards technology change (see Figure 8 and Table 3). It may be that another variable intervenes in this area of human development. For example, students could be developing attitudes about technology outside of school as Sherif & Sherif (1967) found in their research.

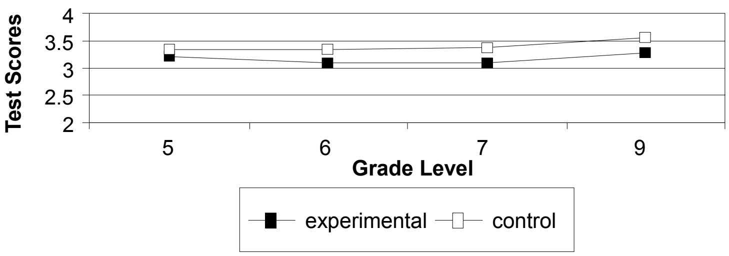


Figure 8. Development in attitudes toward technology (n = 267)

The data show there are significant statistical differences in the affective domain between boys and girls ($p < 0.001$) (see Table 3). The pattern is the same as in the cognitive area. Little change occurs until the middle school years, at which point interest in, commitment to, and respect for technology, increases. The difference between the control and experimental group may be due to the fact that the commitment among boys is higher when they can fully concentrate on the craft area which interests them most and for which they have the greatest capacity. Also, in combined craft, every class (except for the older boys) had similar pre-and-final measurement scores. Attitudes towards technology (emotional engagement) scores remained constant for boys, except for a modest increase after grade seven. Girls' scores, when the new curriculum was introduced, actually went down (2.88 to 2.72), but improved in grade nine when they could concentrate in their own area.

Table 3
Average Scores in Attitudes Toward Technology

Group	Pre measurement	Intermediate measurement	Final Measurement
Experiment group (*n*=116)	3.20	3.09	3.15
Control group (*n*=151)	3.31	3.35	3.51
Boys (*n*=161)	3.51	3.57	3.70
Girls (*n*=106)	2.88	2.72	2.84

Conclusions

The results show that in the psychomotor area, technical thinking achievement improves steadily over the four years. It seems that students excel at psychomotor activities in all project areas, perhaps because they see meaning in their accomplishments, even with small amounts of practice. The research design did not control for normal maturation so it is not possible to state unequivocally that the new curriculum caused these achievement levels.

In the area of technological knowledge (cognitive domain), the results were not as supportive for the post-1994 model of craft education. Remarkable differences were found especially between boys and girls in the younger age group. This finding suggests that a heavier or different emphasis on technical thinking for girls may be required in the curriculum. They (girls) should have equal opportunities to develop their technical thinking at primary school and earlier. One area of need for the Finnish school curriculum is early emphasis on technological knowledge. By comparison, the results in the affective domain followed the same pattern as those in the cognitive. The impact of the post-1994 curriculum on attitudes is problematic. Differences were found between boys and girls in all age groups. Male attitudes toward technology, i.e., emotional maturity, occurred earlier and more quickly than that of girls. This finding corroborates with results found in teacher training (Autio, 1997).

The data from this study suggest that the definition of technical thinking as human ingenuity in problem solving is measurable. Furthermore, motor skill development (spatiality and temporality) is an aspect of technical thinking and human development that can be taught successfully in crafts and textiles programs within schools. In every psychomotor exercise there is a lot of thinking and with every thought and action there is emotion. The combination of all three involves a cleverness, competence, and emotional will. The data, above all, suggest that the relationship between cognitive ability, motor development, and emotional development is one that needs to be recognized and valued in pedagogical terms. What is the relationship between these three inseparable areas of student development, and what are the implications for our understanding of how children learn and develop?

The data also suggest that boys and girls differ in their interests and development with respect to technology. The difference between boys and girls in the affective domain has an influence on girls´ motivation for learning about technology and even on their future career decisions (Byrne, 1987; Halperin, 1992). In developing technology-related education programs, the cognitive differences between boys and girls need to be taken into account. The extent to which girls can improve their technical thinking in the future may hinge on how school programs are designed and implemented.

When curriculum specialists attempt to provide a good balance among attitudes, motor activities, and technological knowledge in teaching technology they should pay much more attention to the pace at which boys develop versus girls. The fact that it is difficult to sustain student commitment to practical problem solving questions through formal education is important to understand and respect. Young students may feel, because of the time and effort it takes to complete a project, that they are not learning quickly enough at this stage of their development. Later, as their competencies and technical thinking improve, motivation and subsequent achievement increase.

Discussion

The 1994 Finnish curriculum of crafts specifies that technical and textile craft should be combined into one subject, which should be taught to both boys and girls over their entire comprehensive school lives. This study suggests that such a recommendation is supportable but that some topics should be taught in homogeneous groups. If girls do require more time for development, they should have some opportunity to learn independently from the boys, perhaps as a pedagogical strategy, e.g., in the design and completion of projects. They should have more opportunities to concentrate on materials and projects with which they are familiar and comfortable. Craft is described as a comprehensive school subject that offers all-round education, develops the skills of the hand and thinking, and teaches pupils to work. Several years after the new curriculum, the tradition of teaching technical craft to boys and textile to girls is as entrenched as ever. Renewal in the curriculum has not changed much but could if curriculum planners understood how a pedagogical strategy and curriculum content are distinctive but complementary. In other words, organize the curriculum and instruction so that students have a personally meaningful experience.

The vision of technology education as a subject of its own at the national level, evolving either partially or entirely from crafts, is a realistic one. Parikka's (1998) three alternatives for implementing technology education in Finnish comprehensive schools could be a possible curriculum conceptualisation. It would be useful though, to classify knowledge in a practical rather than scientific way. For the senior secondary schools this conceptualisation would have to be more experiential and accommodate local community culture and heritage. The tendency for comprehensive secondary schools to be university preparation sites that perpetuate an academic milieu is already widespread. While the study did not directly solicit anecdotal information in this regard some observations and recordings were noted. Some of the boys, for example, made their feelings clear about their learning in crafts compared to other school subjects. They found the learning activities in non-craft subjects to be mindless and meaningless. Interestingly, these boys were the ones who often had the best results in the test of motor skills. Perhaps the preference by some students for experiential pedagogy practiced in craft classrooms warrants investigation relative to the didactic pedagogy characteristic of other subjects. Further study is required.

Given the results of this study, every student in Finnish schools should be given a balanced curriculum that draws deliberately upon examples from everyday life situations as well as from textbooks from the educational sciences. In addition, every student should also be given an opportunity to concentrate more seriously on the craft area that most interests him or her. In light of the different interests held by boys and girls for motor skill development, technological knowledge, and emotional engagement, designing technological studies curricula for different genders in a particular age group is crucial in the policy and planning process. As early as in nursery school, teachers may need to concentrate more on crafts that place equal emphasis on textiles and mechanics, drawing judiciously on projects that are relevant and of prime interest to students.

De Luca (1993) and Williams & Williams (1997) argue that creative problem-solving activities should be an integral part of craft-and-technology education in contrast to teacher-directed reproduction handwork. Others (Wu, Custer, & Dyrenfurth, 1996) suggest that problem solving itself should determine the content and teaching method employed. This is an issue that will require further study and thought in the opinions of the authors. An especially important aspect of education in, about, and through technology, and teacher education, is the opportunity of utilizing fresh ideas and approaches. For example, by adopting alternative pedagogical strategies at the university and comprehensive school levels, it is possible that more could be learned about the value of teaching problem-solving strategies and the relation of those strategies to psychomotor skills and emotional development.

This study shows that a better understanding of what children learn when they exercise their minds and bodies concurrently is important. Learning takes place upon completion of a product but also through reflection in every phase of the technological process. But does current research acknowledge and address this connection? Above all, do children understand that technology (the combining of body, spirit, and mind) is directed by human needs and wants, including their own? Technological and social development, can be reconciled. Every generation needs to understand how its technological culture and its human evolution process interact. The kinds of artistic and technological/practical experience needed to enhance meaningful social progress and to design school curriculum exist. Needed now, in Finland and beyond, is the willingness to further define and commit to an experiential pedagogy and heritage in school programs.

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Learning Good Electronics or Coping With Challenging Tasks: The Priorities of Excellent Students

Moshe Barak

In today's competitive society, the secondary school serves as a crucial stage in acquiring a higher education, a profession, and the social and economic status that these provide. Technology education in high school is the last stage prior to seeking employment and embarking upon a career or seeking further education. Unfortunately, it is an elective program in most countries. Thus, students who do not opt for technology studies in high school miss an essential part of the program. Not studying technology in high school creates a three-year severance—from the completion of technology studies in junior high school until graduation from high school and beginning the process of acquiring a higher education and a profession. Since technology has never been a basic part of education in the eyes of students and their parents, there is a considerable gap between the prestigious image of technology and the actual status of technology education as an elective subject in high school.

The situation in which outstanding students choose to opt out of technology studies in high school severely weakens the status and centrality of technology education. The effort to attract outstanding students to technology studies in high school is the spearhead of efforts to strengthen technology education and enhance its status. Without a cadre of excellent students, technology education may be perceived as being of secondary importance, not only in high school, but also in the entire spectrum of K-12 education.

In Israel, technology education plays a central role in high schools. Approximately fifty percent of high school students major in technology, at different levels, at comprehensive high schools. This system is subject to conflicting pressures. On the one hand, the system is intended to cultivate the excellent students, who are interested in topics such as electronics, computers, and robotics. On the other hand, technology studies in high school have become the main educational framework for students with lower achievement, who take the matriculation exams at the most basic level or finish high school without a certificate that enables them to go on to a higher education. This is a manifestation of the conflict between the prestigious image of technology on the

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one hand, and the perception of technology education as vocational education on the other. For many years, many schools in Israel accorded great prestige to electronics studies and attracted excellent students. However, since the beginning of the 1990s, Israel has undergone several social and educational changes, which have cast a growing shadow on the status of high school electronics studies. Paradoxically, the decrease in the number of excellent students choosing to study electronics occurred at a time when the Israeli high-tech industry was expanding at a dramatic pace, occupying a central role in the Israeli economy and achieving eminent status in world markets.

This article presents a longitudinal research study of teaching and learning electronics at twelve Israeli high schools over a period of four years. The research examines the processes that took place in the field, the pressures and conflicts to which the schools are subjected, and the efforts that they are making to preserve the high standing of electronics studies. Since electronics studies are, in many respects, the “engine” driving technology education in Israel, this research might cast more light on the development of technology education, and result in steps being taken to make the case for technology education in the K-12 curriculum (Cajas, 2000; Lewis, 1999).

Theoretical Background

Most of the literature on the goals and methodology of technology education explore technology education in the broader context of K-12 education (de Vries, 1994; Hill 1997, Zuga, 1999). However, little attention is paid to the unique aspects of technology studies in high schools. This is in inverse proportion to its central role within the general field of education. In recent years we have witnessed a growing recognition of the importance of education in developing higher order cognitive skills such as mathematical/logical thinking, problem solving abilities, and creativity (Glaser, 1992; Rogoff, 1990). More emphasis is accorded to authenticity of learning experiences, open-ended tasks, and teamwork (Barak & Maymon, 1998; Greeno, 1997; Roth & Bowen, 1993). The idea that learning is embodied in activities shaped by social and physical interactions is central to the cognitive apprenticeship approach (Collins, Brown, & Newman, 1989). Part of this point of view is based on making the teacher’s role that of a facilitator and guide rather than a transmitter of knowledge and supervisor of achievements. Contextual learning is a central condition for meaningful learning and for the development of higher intellectual skills (Johnson, 1997; Resnick, 1987). Contextual learning is learning that occurs in close association with actual experience and is tied to the child's experiences and interests. Effective contextual learning results from a complex interaction of teaching methods, content, situation, and linkages with community, neighborhood, or workplace. These concepts are not easily implemented within technology education in high school. As students mature, their fields of interest expand, their life experience broadens, and their expectations from their studies in school in general, and from technology studies in particular, increase. Students in the last few years of high school need greater challenges and a more advanced and sophisticated learning environment, compared to those in elementary school or junior high school. Students at the age of 17 and 18 expect to be dealing with "high-tech" areas such as computers, electronics, and robotics.

Project-based learning is one of the leading models in technology education, with projects aimed at developing a higher level of cognitive skills, creativity, teamwork abilities, self-discipline and responsibility (Barak & Dopplet, 1999, 2000; Cross & McCormick, 1986; Thomas, Mergendoller & Michaelson, 1999). Implementation of project-based learning in high school is more complex and problematic compared to such studies in elementary school and junior high school. Dealing with advanced technological subjects requires careful selection of project topics in accordance with the knowledge and experience of the students and teachers and depends upon the means at their disposal (Barlex, 1994). In high school there is pressure to attain high scores, which, in turn, determine the chances of acceptance to prestigious university faculties. School programs are to a great extent dictated by national exams or detailed standards for learning and performance like those in the United States (AAAS, 1993; NRC, 1996; ITEA, 2000) or England (Department of Education, 1995). These constraints call into question the ability and the motivation of teachers to search for meaningful learning, to foster initiative, and to encourage originality—which are at the heart of technological projects (Lewis, 2000, Atkinson, 2000).

Research Goals and Methodology

The research described in this article is a longitudinal investigation of electronics teaching in Israeli high schools over a period of four years. The research aimed to:

1. Explore the status of electronics studies provided in a comprehensive high school as viewed by teachers and students.
2. Examine the content and methods of electronics studies customary in the field and their implications for attracting excellent students.
3. Identify the causes for the decline in the status of electronics studies.
4. Trace the steps taken to change and bring about innovation in schools and their effect upon the students and teachers.

This study adopted the methodology of qualitative research (Hoepfl, 1997; Johnson, 1995; Lincoln and Guba, 1985; Patton, 1990). This methodology enables one to follow the researched phenomena closely and to examine, in a naturalistic way, as many aspects of the investigated phenomena as possible. In accordance with the concept of qualitative research, questions or specific variables that the research examines were not defined in advance. Instead, maximal flexibility and openness were adopted in order to identify the processes taking place in schools over a period of time in the subject matter taught and methods of instruction adopted in schools, the learning environment, and original initiatives taken in schools over a period of years and their effects.

Research Population, Data Collection, and Analysis

The research was conducted in twelve comprehensive schools where electronics studies are conducted within the comprehensive schools. The schools were selected in order to represent a range of populations and standard of living common in Israel: Large, well established cities and small peripheral towns comprising middle-low socioeconomic classes.

The data for the study were obtained using participant observations, interviews and document evaluation, as detailed below:

1. Visits were made to every school two to three times a year (a total of more than 100 visits). Interviews were conducted with principals, teachers, and students, as they were working in the lab.
2. The researcher actively participated in ten regional meetings of teachers as a part of a program of in-service training courses and workshops. The subjects studied in these workshops and the matters raised by the teachers were documented as authentic information of the research.
3. Informal conversations were held with approximately 30 electronics teachers, most of them participated in previous research projects headed by the researcher. Close links between the researcher and teachers is a desirable element in qualitative educational research. These links facilitate the transfer of authentic information such as instructional problems, feedback on in-service courses in which the teachers participated, or personal concerns in view of the changes taking place in the schools.
4. Observations were conducted in two schools while the national examinations of the students on their final project were being conducted. Discussions were held with the students and the examiners during and after the examinations.
5. During the last year of the research, semi-structured group interviews were conducted with the three to four electronics teachers from six of the schools. The teachers were asked to summarize the status of electronics studies in their school and the impacts of the changes that were attempted in recent years. These interviews were recorded, and in the course of the discussion a written summary was prepared with the assistance of the teachers.
6. Schools provided statistical data on students' achievement in the matriculation examinations in electronics over a period of four years and on late registration of students for electronics studies.

The analysis process and the development of conclusions were iterative, and the subjects of research were also included: Every interpretation or conclusion formulated was examined and verified through repeated discussions with students, teachers, and principals. The extended observation time, peer debriefing, member checks, and the use of multiple data sources helped ensure credibility of the findings (Guba & Lincoln, 1994). Thus, the research methodology and procedures were in line with the characteristics of qualitative research that Hoepfl proposed (1997, p.49): "Qualitative research uses the natural setting as the source of data. . . .The researcher acts as a 'human instrument' of data collection. . . . The research has an emergent (as opposed to predetermined) design."

Findings

The Framework of Electronics Studies in Israeli High School

Students in Israeli high schools study electronics for about sixteen hours per week for three years (grades 10, 11, and 12). At the same time they take general subjects such as mathematics, English, literature, and history. Electronics studies comprise basics in electricity, analog electronics, digital electronics, microprocessors, control systems, and communications. Each subject is studied for three or four hours per week, for two years. At the end of high school the students take two or three matriculation exams in electronics. The grades of these exams are credited toward acceptance for university or college studies, although some of the academic institutions assign more weight to achievements in mathematics and physics.

Attitudes of Teachers and Principals Regarding Electronics Studies in High School

In a series of preliminary meetings held with principals and teachers, eight of the twelve principals expressed concern about the state of electronics studies in their school. They presented data showing a decline in the number of excellent students choosing to major in electronics. For instance, whereas ten to fifteen years ago excellent students "fought" for a place in electronics classes, now more and more students in electronics classes are on an intermediate level. Teachers used terms such as "urgent aid" and "rescue measures." At a meeting with twelve teachers, in preparation for a proposed project in northern Israel (Barak, 2001), the teachers made over 30 different suggestions for improving electronics studies. They suggested, for example: Changing teaching methods, accelerating the use of computers, initiation of projects, improvement of labs, reducing the students' workload, and "marketing" electronics studies to students at the enrollment stage. In the present study, the teachers sought to enhance their pedagogical knowledge (Shulman, 1986) rather than their knowledge in specific subject matter, as was found in a previous program put forth a decade earlier for the same region.

Conventional Electronics Studies

The main component of electronics studies is the theoretical "talk-and-chalk" lesson. Lab experiments, aimed at "validating the theoretical principles," lag weeks or months behind theoretical studies. At the beginning of the 1990s, for the first time, the Ministry of Education published specifications (a sort of "standards") for the achievements required of students in theoretical and laboratory electronics studies. The official program spells out in detail the requirements for each build the circuit lab experiment, such as: "The student should draw a sketch of the circuits… connect the measuring instruments…

measure input and output voltage… draw a graph… calculate the amplification and write a report." Teachers and students hold a list of mandatory experiments, and all lab studies are determined in accordance with this list. Some of the experiments are conducted only with the use of computerized simulation.

In the course of the visits to schools, the students were asked to explain what they were doing in the laboratory, why they had chosen to study electronics, and what their expectations were. The students were freshmen or in their second or third year of high school. Some students were interviewed two to four times over the course of their electronics studies. When the students were asked to explain what they were doing, the typical answer was "I'm performing an experiment with a diode . . . a transistor . . . an OR gate." In other words, the students conceived the topic of the experiments in terms of the particular components they employed. They gave theoretical examples of the use of these components in daily life, but not a single school examined possessed appliances such as radios, tape recorders, or alarm systems in their laboratories. As the students advanced through the 11th and 12th grades, the studies became more and more abstract, and a growing gap emerged between the electronics studied in school and electronics in everyday life. For example, a 12th grade program was comprised of a course in communications systems. The students drew a block diagram of a transmission–reception system, wrote down the formulae of AM and FM signals and conducted experiments using a signal generator and oscilloscope. However, the experiments were conducted at low frequencies, such as 10 KHz. None of the school laboratories were equipped with a transmitter of commercial frequency, which could be checked with a commonly used radio receiver. In one case, the teacher improvised a demonstration of a FM broadcast at 100MHz, which was received on the portable radios some of the students possessed. They immediately started to ask questions, such as the distance over which it was possible to broadcast; how much a "real" transmitter, power amplifier, and antenna would cost; and how to set up a private radio station. This example shows that the conventional program for electronics studies in Israel is weak in one of the main purposes of technology education: linking what is learned in school with the real world and dealing with topics that interest the students and arouse their imagination.

Students' Attitudes Toward Electronics Studies

As previously mentioned, electronics studies in high school are elective, giving the students additional points for the Israeli Matriculation Certificate—the "Bagrut." Therefore, students' answers to questions such as "Why did you choose to study electronics?" or "What are your expectations?" reflect to a large extent the status of this field in Israeli education. Discussions with students at the end of their first year (10th grade) focused on expectations for the future. Although they study only basic subjects in their first year, they expect to study more "practical" topics as they progress. They regard electronics as an important and interesting field in which they may find work after graduation. For most students the first year studies are interesting, but not exciting. The 11th and 12th grade students study a number of advanced subjects in analog and digital electronics, but they hardly see the correlation between one subject and another, and how they all relate to everyday electronics applications. Electronics students spend two or three hours more per day in school than those studying only scientific or humanities subjects. Most of them do so willingly, in the hope that it will benefit them in the future. Many of the excellent students, who concurrently study mathematics and physics at the highest level, are disappointed. They expressed opinions such as, “If I had known what we would be studying, I would not have chosen electronics studies”; “This is not what I expected”; “I don’t really need this for my matriculation certificate.” In one of the schools an excellent student said that he did not recommend electronics studies to his brother because “The studies are difficult and not interesting.”

Efforts for Change and Renewal

In order to cope with the decline in demand for electronics studies by excellent students, as described above, nine out of the twelve schools examined in this research took steps to improve electronics studies. For example, teachers gave students exercises in searching the Internet for data bases, circuits and mini-projects; schools offered electronics students enrichment courses in computers, such as HTML and C programming, beyond the formal curriculum requirements; schools renovated their laboratories and installed new equipment such as computers, digital oscilloscopes and programmable logic controllers; laboratories were equipped with air conditioning and new furniture, some of them designed like those in Israeli high-tech companies; and mini-projects were introduced into first year (tenth grade) studies. The students themselves built small electronic products such as an alarm or power supply.

Introducing Final Projects as Part of Matriculation Exams

Until about ten years ago each student was required to complete a final project as part of the requirements for receiving an Israeli Matriculation Certificate. Veteran teachers remember this as the “golden era” of electronics studies in Israel. “We used to remain with the students in the laboratory until 10 o’clock at night,” recalled one of the teachers nostalgically. Of the twelve schools studied in this research, nine took upon themselves to replace one of the conventional matriculation exams in electronics with a final project in electronics in the 12th grade. This decision was quite difficult, since principals and teachers were apprehensive about taking a step where final results were uncertain. “Why take a chance?” asked one of the principals. “The students’ achievements in the regular exams are excellent. We cannot risk their matriculation certificates.” In one of the schools the electronics teacher claimed that “The projects are time-consuming, making it impossible to teach the theoretical material and perform the experiments.” He focused on the national exams by drilling the students in the compulsory experiments, claiming that this was the best way to succeed. Despite the vacillation, two hundred twelfth grade projects were completed in nine schools in one year, whereas none had been completed during the previous year. The following are some examples of events in schools involving final projects:

- The teachers and students from six schools participated in a preparation camp during their summer vacation.
- When projects were approaching their culmination, students and teachers voluntarily remained at school in the afternoons, evenings, and during weekends.
- The standard of topics dealt with by students, in many projects, considerably surpassed what was being taught at school. For example, one of the students conducted a project entitled "Peripheral Protection of a Museum." He built a complete model of a museum including detectors on doors, windows, and exhibits. The system comprised smoke, temperature, and humidity sensors. The whole system was operated by means of programmable logic controllers (PLC). The student devoted days and nights to obtaining information on the sensors from the Internet, building the electronics circuits, and trouble-shooting. He dealt on his own with matters such as measurement, signal amplification, calibration, digital to analog conversion, and programming. This student achieved the maximum that could be expected as far as motivation, initiative, creativity, and diligence. Although he had studied most of the specific topics for the project on his own, the theoretical knowledge of electronics that he had learned at school provided him with a foundation.
- Not all of the projects were on the same level. Some were trivial, like building an electronic circuit that was taken from a popular journal.
- From the above-mentioned examples it is apparent that projects varied considerably in scope, content, and degree of complexity.
- There were occasions when the students changed or expanded their projects on their own initiative without the teacher's consent. Students purchased components or specific tools with their own money in order to further and improve their project.
- Out of approximately two hundred students who undertook a project, only a handful received a low grade or failed in the final matriculation exams.
- The vast majority of the teachers are engineers. While they demonstrate fundamental professional knowledge in all basic electronics subjects, they are not up to date on matters such as advanced programming or digital communications systems.
- A close look at the work of students reveals that they use the "classical" tools and methods for electronics design, drawing, simulation, construction, measurements, and documentation.

- In a concluding discussion with teachers, one of them expressed the following: “The projects put us under pressure. The students were accustomed to the idea that we (the teachers) know everything and expected us to immediately solve every problem. When they realized that this was not the case, situations that we had not previously encountered developed.”
- In two schools, 12th grade students presented their projects at a get-together with 9th grade students who were about to enroll, and were accompanied by their parents. One of the teachers said: “We must carry out projects next year too so that we will have something to show the 9th graders during their enrollment for school.” In other words, the execution of projects by the 12th graders developed into a means of enhancing the image of the field and attracting new students.
- From information received in the year following the visits to the school, the 12th grade students in all nine schools intend to submit a final project instead of taking the conventional matriculation examination.
- Four of the nine schools reported a significant rise in the number of freshman students desiring to study electronics.

The National Supervision Perspective

The processes described above evolved as an independent initiative taken by schools on the local and regional levels in an attempt to upgrade their programs and to attract excellent students to electronics studies. The national supervision authorities encouraged the introduction of projects into the matriculation exams in electronics and presented the schools’ achievements at teachers’ conferences. Concurrently, a process of upgrading the electronics curricula was started by introducing new and advanced topics such as digital communication, computerized control, robotics, sound processing, and computer vision. The new curriculum aimed at increasing the significance of the use of computers in performing experiments, measurements, and simulations. The study of digital electronics will be carried out through programmable logic devices such as ALTERA, and the work with individual components will be reduced. The guiding principle is the elevation of the level of studies, and matriculation examinations—even if this gives rise to a temporary decline in the number of students enrolled in electronics in the high schools. The title of electronics studies in high school (10th – 12th grade) has been changed to “Electronics and Computer Engineering”.

Discussion

This research examined the processes occurring in electronics studies in a group of Israeli schools over a period of four years. The reference is to technology education within the comprehensive high school. Parallel with the study of technological subjects, which comprise approximately one-third of school hours, students learn a wide variety of general subjects. The research was undertaken on a background of a downward trend in the number of excellent students opting for these studies and continuing until the completion of high school. The objectives of the research were to explore the processes occurring in the teaching of electronics in schools, including conventional curricula and pedagogical techniques, changes and innovations implemented in schools, and their influence on teachers and students.

In order to understand present trends in electronics studies in Israel, one must think back 10-20 years ago to the time when electronics studies flourished and reached a peak of success. There were a number of reasons for this. They include the flourishing of the electronics industry in Israel, which created a prestigious image for this area of study; school studies combined theory, laboratory work, and projects; most of the studies took place in laboratories that were more sophisticated than those serving other school subjects; the students were involved with subjects at the cutting edge of electronics at that time; energetic teachers, with a great deal of professional experience spearheaded the subject and influenced the national supervisory authorities who sometimes lagged behind developments in schools. Despite the heavy burden that electronics studies imposed on students, they flourished for a period of some two decades. This picture changed gradually during the last decade of the 20th century. While there has been an accelerated development in computers and computer sciences, electronics studies appear to remain behind. Schools suffered a continual cutting of study hours, as well a shortfall in resources for maintenance of laboratories and renewal of components. There was also a hidden pressure to reduce the workload on students. In the wake of the publication of official "standards" for electronics studies, all schools adopted the minimums. The laboratory studies were confined to the implementation of a list of obvious experiments on which the students were to be tested in the matriculation examinations. All of these have resulted in a sharp reduction of lab studies and almost complete elimination of independent student projects. According to the teachers themselves, in retrospect, this was the main reason why independent and original initiatives of schools to advance electronics studies became more and more infrequent. It took five to ten years before schools noticed the gradual retreat of the status of electronics studies. Some of the teachers made efforts to introduce the use of computers into electronics studies, especially through the wide utilization of computer simulations for the analysis and design of electronic circuits. All too often, however, computer simulation served as an alternative to practical laboratory work and distanced students even more from the world of 'real' electronics.

The critical phase in the efforts to introduce innovations in schools was the inclusion of projects into the 12th grade. The fact that some two hundred students from twelve schools simultaneously submitted a final project as an alternative to conventional matriculation examinations proves that the time was ripe for this change. The advantages of the project approach were etched in the memories of teachers from earlier times. The most important step was to stimulate teachers and principals to start this process and to overcome the hesitations, which were based mainly upon the question of preparing the students for the national matriculation examinations. However, after the first two schools began, the idea gathered momentum, and additional schools joined the process. Students' and teachers' work on the projects introduced a breath of fresh air into the classrooms. Despite the extra burden involved in working on projects (in comparison with studies toward the conventional national examination), few students dropped out prior to completing their project. The meetings with students involved in projects, the discussions with teachers and principals, and the events that took place in schools after the introduction of projects in the electronics curriculum proved that this was a turning point in the status of these studies both inside and outside the school. The introduction of projects to electronics studies affected the community and served as the main trigger for the upward trend in the demand for electronics studies among new registrants to the school.

A careful observation of the projects with which students are involved indicates that technology studies and the implementation of projects in high schools vary considerably from situations in which younger students are involved. The more outstanding students seek complex tasks such as those combining analog and digital components, sensors, microprocessors, peripheral components, and programming (e.g., assembler, Pascal, or C). The students use "professional languages" as well as engineering tools such as: physical variables, formulae, drawings, literature, technical catalogues, databases on the Internet, and computer simulation. The instrumentation in a high school electronics laboratory is no different from that in a college electronics lab or in industry. All of the teachers who instruct the students are electronic engineering graduates themselves, and some of them have a background in industry. In many classes there are students whose parents are electronic engineers, who assist them with their projects. As mentioned earlier, not all the projects undertaken by students were at a high level of originality or complexity. When tens and even hundreds of projects are undertaken, it is natural that there would be a variety of levels and diversity among students, teachers, and schools. However, the fact that all the projects were conducted under the wide umbrella of professional electronics reflected on the motivation of the students and their achievements.

Conclusions

There are those who would question whether the in-depth study of electronics, or any specific technical field, leads to the achievement of the goals professionals set for technology education. The answer is that teaching good electronics by itself is not enough. What matters is the kind of task with which we confront the students. Outstanding students elect to study electronics in high school in anticipation of dealing with the design and construction of sophisticated instrumentation and advanced systems for electronics, communication, control, and robotics. However, more often they find themselves studying a series of unconnected theoretical subjects and undertaking standard laboratory experiments, the results of which are obvious from the outset. We attempt to raise students' motivational levels by trying to convince them that, after the basic studies, they will be able to engage in what really interests them. But in fact they never seem to achieve this. The result is disappointment and frustration. Educational literature has emphasized for years that the role of education is to develop higher order cognitive skills and intellectual competencies. Schools continuously struggle with the question of how to arouse the interest of students in their studies and how to foster curiosity, initiative, and consistency in confronting aims and challenges. These are unquestionably the declared objectives of technology education. The present research shows that implementation of pedagogical methods that develop students' intellectual capabilities is an overt as well as covert demand of the students themselves and not merely a matter of a determination from above. Outstanding students seek challenging tasks, open-ended assignments, freedom to experiment, to err and learn from mistakes, and to reach their own capability. A major stumbling block preventing schools from adopting this conception in the high schools is what appears to be the risk of confronting students and teachers with open, challenging assignments.

One should not ignore the fact that high school studies are largely oriented toward the national matriculation examinations. On the face of it there appears to be a conflict between realizing the expectations of students to deal with advanced technological subjects and the responsibility of teachers to help them achieve high marks that will open the portals of desirable universities. Apparently, students and teachers must choose between confronting the unknown or the well-trodden path. The results of this research demonstrate unequivocally that deep at the heart of the matter, excellent students are prepared to invest tremendous effort in technological studies provided they anticipate an interesting assignment. They are not, however, willing to engage in technological studies in which the objective is to obtain another good mark in the final certificate. This conclusion is in consonance with what is known to educational and psychological literature, namely that creativity, the motivation to study, and consistency in action are inspired by intrinsic rather than extrinsic gratification (Sternberg, 1988; Hennessey & Ambile, 1998).

Students cannot grapple with open-ended assignments and challenging tasks unless they acquire a foundation of theoretical knowledge and practical expertise in a specific area, such as basic electronics or control systems. There is nothing wrong with theoretical studies and conventional laboratory work as part of the school day. Educators and curriculum developers should identify core curricula and focus on this, but there is no need for the comprehensive study of methods for analysis and design, as is so often demanded. What is required is the optimum balance between basic theoretical studies and grappling with open-ended assignments and projects throughout the period of studies rather than just at the final stage. This is the key for transforming high school technology studies into a desirable objective for the most outstanding students.

A Final Observation

Two medical students, high school graduates in electronics, were invited by the school principal to meet with new students and their parents. One of the parents asked them why, after putting so much effort into the study of electronics in high school, they did not continue in the same field in university. The graduates' answer was that studying electronics in high school does not necessarily mean continuing in this field later. Once they had graduated from high school, they could have been accepted into any field of academic studies in the university. Furthermore, they felt that their electronics studies equipped them with the knowledge and tools to succeed in medicine and perhaps to be better doctors.

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Elementary School Students' Understandings of Technology Concepts

Robert S. Davis, Ian S. Ginns, and Campbell J. McRobbie

Elementary school teachers and teacher educators have expressed concerns about what students learn as they engage in design and technology activities. This study was designed to identify students' understandings of selected technology concepts, and changes in those understandings across a range of age levels corresponding to grades 2, 4 and 6 at elementary school. Following an extensive interview program and subsequent data analysis, it is argued that commonalities and variations in understandings exist within and across age levels. The identification of these commonalities and variations is examined for their implications for classroom teachers, the development of more appropriate design and technology programs, and preservice and inservice teacher education.

Background

A framework for the development of design and technology curricula by the various states in Australia has been established in two documents—a national statement and a national profile in Technology Education (Curriculum Corporation, 1994a, b). Technology has been defined as involving "the purposeful application of knowledge, experience and resources to create products and processes that meet human needs" (Curriculum Corporation, 1994a, p. 3). This framework, in common with other international and national statements (e.g., American Association for the Advancement of Science (AAAS), 1993) and curriculum documents (e.g., Queensland Schools Curriculum Council (QSCC), 2000), stressed the importance of providing students with opportunities for participation in meaningful learning experiences in which they could draw upon their existing knowledge of materials, tools, machines, and systems, as well as gather and use information from a variety of sources. Further, the framework indicates that the meaningful learning experiences should facilitate the engagement of students in problem solving to produce an end process, product, or artifact, thus enabling their construction of new and deeper understandings of design and technology concepts and processes. The intentions of the framework were linked with outcome statements that reflected the

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attainment by students of a range of problem solving skills, manipulative skills, and, in particular, understandings of design and technology concepts.

A relatively small amount of research has been done on students' understandings of design and technology concepts, or technical knowledge (Bennett, 1996; Gustafson, Rowell, & Rose, 1998; Levinson, Murphy, & McCormick, 1997; Twyford & Järvinen, 2000). This limited research base represents a constraint for teachers, teacher educators, and curriculum developers who wish to capitalize on the rich and varied content of technology. Clearly, more research in this area is needed to support effective implementation of technology programs and enhance the preservice and inservice training of teachers.

It may be difficult to define what is concept knowledge in design and technology because of the amount of personal knowledge used at various stages in the design process (McCormick, 1997). A perception also exists that design and technology is underpinned by science-related concepts and, consequently, science education research may already provide some information about concepts in design and technology (Gustafson et al., 1998). However, we argue there are concepts that relate identifiably to design and technology that may already have been explored in science education research, but not in technological settings. For example, although science education researchers have probed students' understandings of the nature and behavior of matter (Kruel, Watson, & Glazar, 1998), we are unaware of research into students' understandings of properties of matter, which should be kept in mind when choosing materials to construct an artifact. Technologists may have to take into account one or more properties of materials, such as strength, flexibility, conductivity, and durability, or so-called "functional" properties (Cajas, 2001), when deciding which material to use for the production of an artifact. Consequently, trade-offs between various properties become an important component of selection and decision-making processes. A useful insight from science education research that can inform investigations into students' understandings of materials in technological settings is that young students tend to link their concept of matter to tangible properties such as weight or heaviness (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Smith, Carey, & Wiser, 1985).

Gustafson et al. (1998) reported grade 3, 4 and 5 students' understandings of elements that contributed to the structural stability of towers, including ideas such as adding a heavy base, adding feet to supports, thickening supports, and reinforcing joints. The strength of materials from which towers are constructed, as well as the design of bracing, are also elements that contribute to the stability of towers. Ideally, students should be able to understand the complex relationships between knowledge of the properties of materials, stability, and bracing during the construction of worthwhile artifacts, or the achievement of quality solutions (National Association of Advisers and Inspectors in Design and Technology, 1994).

Because material properties (e.g., strength), stability, and bracing are important in many technological settings and activities, we contend that an understanding of these concepts should be part of an identifiable knowledge base for students, as well as teachers of design and technology in elementary school. Jones, Moreland, and Chambers (2001) asserted that the notion of a technology knowledge base for teachers is pivotal for effective teaching and assessment in technology education. Their study included the development of a planning format for teachers that assisted in the identification of specific concepts required by teachers in different technology areas. Likewise, the importance of conceptual knowledge, particularly in its relationship to procedural knowledge, has also been emphasized (McCormick, 1997). In addition, Lewis (1999) asserted that an understanding of the technology concepts students possess is an important prerequisite for better teaching.

When confronting the issue of a limited research base on students' understandings of design and technology concepts, it is useful to draw upon the methods and techniques used in science education research that have led to the development of a large quantity of research findings about students' understandings of fundamental science concepts. These research findings have contributed significantly to learning theories and practice in science (e.g., Yager, 1991), curriculum development and implementation in science (Driver, Leach, Scott, & Wood-Robinson, 1994), and preservice and inservice teacher education.

Driver et al. (1994), in their review of research on the understandings of science concepts of students in the age range 5-16 years, proposed that "learning within a particular domain can be characterized in terms of progress through a sequence of conceptualizations which portray significant steps in the way knowledge within the given domain is represented" (p. 85). They used the phrase "conceptual trajectory" to label this sequence of the most frequent conceptualizations at different age levels, the trajectory being evident in the progression towards more scientifically acceptable views of the relevant concept. Further, the conceptualizations are indicative of possible groupings or categorizations of explanations of phenomena. To illustrate such a trajectory, the most frequent conceptualization of the youngest students is that air exists only as "wind" or "breeze." The notion of air as a material substance is the most frequent conceptualization of older students around the mid-point of the age range, followed by a general recognition in the oldest students that air is not only a material substance but has mass as well. Driver et al. claimed that such conceptual trajectories have important implications for curriculum decision-making within the relevant science knowledge domain.

We suggest that cross age studies of students' understandings of technology concepts using methods and techniques similar to those employed in science education research are warranted. If age-related conceptualizations exist in design and technology, and there appears to be a progression to more abstract conceptualizations with increasing age, the findings could be used to inform curriculum development, and to enhance preservice and inservice teacher education programs. Further, practicing teachers, in particular, would be the main beneficiaries of such information because of its direct application to the planning and implementation of technology teaching and learning experiences, and to the assessment of students' learning.

Students' understandings of selected technology concepts, and changes in those understandings, across the age range 6-13 years were investigated in this study. The paper reports the findings related to the concept of strength of materials and the concept of stability, and analyzes the commonalities and variations in understandings of those concepts across the age range. The implications of the findings for the development of design and technology programs in the elementary school curriculum, and in preservice and inservice teacher education will be examined.

Methodology

The research methods adopted involved the use of interviews-about-instances (Osborne & Freyberg, 1985). This technique involves presenting a student with artifacts or pictures to explore concepts that he/she associates with a particular label. The common elements and idiosyncrasies of students' ideas are identified from transcript analysis. This methodology has been used to identify students' understandings of a wide range of fundamental science concepts such as material properties (Dickinson, 1987), change of state (Stavy, 1990), properties of air and gases (Benson, Wittrock, & Baur, 1993), and earth and gravity (Vosniadou & Brewer, 1992).

Participants

A total of 92 participants, maintaining approximate gender balance, were drawn from each of three separate year levels in each of six randomly selected elementary schools. The samples of students were drawn from grade 2 (*n*=27), grade 4 (*n*=37), and grade 6 (*n*=28), which spanned the age range 6 to 13 years. All participants were interviewed using the interview-about-instances approach. Data were collected over a three-month period.

In preliminary discussions among the authors, an interview protocol was developed, which was trialed with the first ten interviewees. Minor modifications were made before proceeding with the remainder of the interviews. All students were interviewed individually by one author (RSD). The interviews lasted from 15 minutes for the younger year levels to 20-25 minutes for the older students and were conducted in a withdrawal room adjacent to the relevant classroom. Students were selected by their teachers as being representative of students in their respective classes. No demographic data were collected from the students except age and gender.

In the interviews, each participant was presented with a series of models and pictures of objects that the student might associate with a label—examples of bridges, bicycles, and carry bags were used. Questions designed to probe the student's understandings of materials and stability followed a general framework for guidance as shown below:

- *Tell me as much as you can about this object, what it is, how it is made, and what it is made out of. (At the same time students were shown an artifact such as a model bridge constructed out of wood.)*
- *If you were building this bridge [type] to carry cars and/or pedestrians, what material(s) would you build it out of and why?*
- *Is this bridge stable? If not, explain how you would make it more stable.*
- *How do the changes you have suggested make the bridge more stable?*

The students were asked these questions in a manner that was responsive to their age and language ability. The students were not probed further for their sources of information but in some cases prior experiences did seem to inform their explanations.

The open-ended questions were intended to focus students' attention on a model and/or pictures of an artifact. The model bridge utilized in the interviews was a truss bridge, approximately 40 cm in length and 25 cm height, and constructed of lengths of wooden dowels. The dowels were joined with small nut and bolt fasteners; twine was used to attach cross members to form part of the deck of the bridge. The deck was completed using a strip of high-density rubber, which was not fastened to any part of the structure. interviews were audiotaped for coding and analysis. Preliminary interviews revealed more constructive talk was elicited from the students using the bridge and associated pictures than was the case with other sample artifacts. Hence, for the purposes of this paper, only the findings relating to students' responses to the questions about the model bridge will be reported.

Analysis of Data

The analysis of explanations was undertaken through an ongoing examination of data after each set of interviews was completed. For example, the students' responses to the open-ended questions, such as the second example question above, were examined for the understandings evident in their explanations. The range and kinds of explanations were also noted. Explanations that were based on a similar object or idea were grouped together. This grouping of explanations is similar to the possible grouping or categorization of explanations of phenomena that comprised Driver et al.'s (1994) work on most frequent conceptualizations at different age levels, and conceptual trajectories. Disagreements on assigning explanations to a particular group were resolved by further discussion until a consensus was reached. The final analysis of explanations involved a review of the students' explanations and the assignment of these explanations to relevant groups. From the total body of data, groups of explanations for the three age levels included in the study were derived, and progression in terms of increasing abstractness of the groupings was noted.

Findings

Insights into students' understandings of the selected technology concepts are presented in this section. Exemplars of grade 2, grade 4, and grade 6 students' responses to relevant questions are used to illustrate some of the commonalities and variations in their explanations and how the groups were derived. All names used in the discussion are pseudonyms.

Materials and Material Properties

Initially, all students were asked to tell the interviewer as much as they could about the model bridge. Most students recognized the artifact as a bridge and continued on to identify and describe the materials used in its construction. Three students (two grade 2, one grade 6) had to be told what the object was.

Commonalities were noted in the students' explanations when they were presented with the scenario of building a bridge on a larger scale to carry cars or pedestrians and were asked to describe and justify what changes would be necessary to achieve this. One commonality was the suggestion by most students that the bridge would have to be built out of a material (or combination of materials) that was stronger than the wood from which the model bridge was built. The property of strength was referred to directly by the students and/or could be inferred from the justifications provided by the students for the use of different materials, as evident in the following extracts from interviews (I = interviewer; R = respondent).

I: What are we going to build (the bridge) out of?
R: Steel.
I: Why?
R: Cuz, wood's not strong enough to hold a car. (Peter, grade 2)

I: (after discussing certain changes suggested) So, you wouldn't make it out of wood?
R: (laughs) No.
I: Why not?
R: Cuz, cars could . . . like the bridge would collapse if it was made of wood. (Tahnee, grade 4)

I: What would you change (about the bridge)?
R: This bit bigger and the wood a bit thicker. Made out of steel.
I: Thick wood or steel or both?
R: Make it out of steel.
I: Why?
R: It's heavier and you can't really bend it. (Denice, grade 6)

While the material property of strength could be described as one commonality noted across all age levels in the study, variations were observed in the students' explanations for material strength. One variation could be described as a naïve explanation, indicative of a limited understanding of material properties (e.g., Sharon – grade 2).

I: What's so good about steel?
R: Because it doesn't break.
I: Why doesn't steel break?
R: Because it's made out of plastic and it doesn't break.

Denice's explanation noted earlier, demonstrates another variation, that of equating strength of material with heaviness, or weight. Similarly, Erica (Year 4), in the following exchange equated strength with heaviness and also attempted to describe the composition of the metal.

I: Why?
R: Because it's stronger.
I: I wonder why metal's stronger. What is it about metal that makes it stronger?
R: Because metal is heavier and it's just made out of heavy—really heavy stuff.

Students' explanations that referred to the hardness of metal and concrete/cement represent another variation noted. Helen (grade 2), when asked why metal was stronger, replied that "if you get thin bits of wood you can snap them but you can't metal." In this explanation she linked strength and the breakability of materials, and compared the respective properties of wood and metal. Helen could have drawn from personal experience for this explanation.

Even though the explanations provided by Denice, Erica, and Helen varied, we grouped these explanations together because the students attempted to articulate their understanding of the strength of the material out of which they believed the stronger bridge should be constructed. They did not refer solely to the lack of strength of wood as a basis for their justification, hence this group of explanations has been labeled as *Non-artifact related*. Other groups of explanations of material strength that emerged from the data were *Naïve*, *Artifact related*, and *Particle related*.

Each student's explanation was analyzed and assigned to a relevant group of explanations. The percent frequencies of students' explanations in each group are shown in Table 1 by age level. The order of these groups, from left to right in the table, is, arguably, representative of increasingly abstract explanations. In the case where a student's explanation appeared to be linked to two different groups, the explanation was assigned to the more abstract of the two.

Table 1
Percentage Frequencies of Types of Explanations with Age – Material Strength[#]

Grade level	Naïve[1] (%)	Artifact related[2] (%)	Non-artifact related[3] (%)	Particle related[4] (%)
Grade 2	11.1	81.5	7.4	0.0
Grade 4	0.0	81.1	16.2	2.7
Grade 6	0.0	46.4	46.4	7.1

[1] Inappropriate explanation in relation to material properties; [2] Explanation associated specifically with presented artifact; [3] Explanation associated with physical properties of material chosen by student; [4]Explanation indicative of some formal, though limited scientifically acceptable understanding.
[#] Variations from 100% due to rounding.

Examples of explanations from each of the groups will now be presented and described. Firstly, three grade 2 students appeared to be able to identify materials but were unable to discriminate between the properties of different materials. Sharon's explanation has already been described, and a second instance is presented in the following extract from the interview with Melanie (Year 2).

I: If we made this bridge out of metal, would it be a strong bridge?
R: Yes, because metal's like timber.
I: How is it like timber?
R: Because they're both made with metal and stuff, and timber's a little bit stronger than metal.

Clearly, both Melanie and Sharon need to develop understandings that will enable them to discern that different materials have different properties. We have labeled this group *Naïve* as they have inappropriately connected the properties of two dissimilar materials when talking about material strength.

A second group was evident in the students' explanations for choosing steel (or metal) in terms of the lack of strength of the wood used in the construction of the model bridge. The majority of grade 2 students (e.g., Peter) and grade 4 students (e.g., Tahnee) recognized that a material such as steel was suitable for the construction of a stronger bridge, but then referred to the lack of strength of wood when attempting to explain their decision. We can infer that they were able to discriminate between the strength of steel (or metal) and the strength of wood and make judgments about the suitability of each material for the construction of strong bridges. However, the basis of their response was the presented artifact. Hence, we have identified this group of explanations as *Artifact related*.

The third group, *Non-artifact related*, was evident in students' selection of the material and the justification of their selection based on a property of the material itself. Denice's justification for using steel because it was heavy and does not easily bend was mentioned earlier. Similarly, Trevor was able to describe the characteristics of the metal he would use to build a strong bridge and elaborated on how that metal might become less strong over time.

I: What are the characteristics of metal?
R: It doesn't crack when you, like, use it on something, it's a lot tougher.
I: What do you mean by tougher?
R: It doesn't break as easy. You have to cut it to break it, unless it's rusty.
I: What do you mean by rusty?
R: Corrodes it away and makes metal soft.

Two grade 6 students were able to extend their justification of the material selected based on a property of the material itself, into a consideration of the particulate nature of the material. For example, Mary provided an explanation based on the material she selected for building a stronger bridge (concrete), and then elaborated by talking about molecules being present in concrete, when questioned further.

I: You said concrete. Why would that be a better material?
R: Because if you had a fire it would not burn down. And it'd be a lot stronger. And you can't bend it or anything.
I: What is it about concrete that makes it stronger than wood?
R: Um . . . it just is.
I: You said it (concrete) doesn't bend.
R: Because it sets really hard because it has all these molecules and stuff in it that makes it set really hard.
I: What do you mean by molecules? What's happening? What's your understanding of that?
R: Particles and stuff that join up and make it hard.
I: Could I see these if I cut it in half?
R: No.
I: Why not?
R: 'Cause they're too tiny.
I: So it's these tiny little things that are making it strong? Well how's that different to wood? Because wood would be made up of these tiny things as well wouldn't it?
R: Yeah.
I: So why isn't wood as strong as concrete?
R: I don't know. Because . . . you have to . . . it's kind of hard to explain. It's just the way it is.

It is acknowledged that this interpretation may be challenged on the basis that Mary's explanation is not canonical science, and that she may not have been able to sustain the explanation under further questioning. We argue, however, that at the very least her explanation may indicate an awareness of the inadequacies of prior explanations and a need to seek a more formal understanding. An interesting feature of Mary's case is that her initial explanations could be deemed as being *Non-artifact related*. Further probing provided her with the opportunity to articulate a more abstract explanation, hence, the fourth group, *Particle related*, was formed to accommodate such explanations.

Trends are evident in the percentage frequencies of groups shown in Table 1. The frequencies of *Naïve* explanations and *Artifact related* explanations decrease with age, although the differences in percentage frequency from grade 2 to grade 4 for the latter are small. On the other hand, percentage frequencies of *Non-artifact related* explanations and *Particle related* explanations increase with age.

Explanations that refer to the presented artifact (*Artifact related*) are the most frequent for grade 2 (81.5%) and grade 4 (81.1%) students. Explanations that refer to the presented artifact (*Artifact related)* and the students' material of choice (*Non-artifact related)* are the most frequent explanations for grade 6 students (46.4% respectively). This consideration of most frequent explanations at different age levels is similar to Driver et al.'s (1994) conceptual trajectory discussed previously. From this analysis, we suggest that there was a change in the way students conceived the problem represented in the stimulus question, thus many grade 6 students were able to provide explanations that went beyond the perceived limits of the presented artifact.

Stability

Commonalities were found in students' explanations when asked how they would make the bridge more stable. Typically, the explanations referred to a way of, or approach to, solving the problem; for example, the use of a binding material, usually cement or concrete, to stabilize the pylons of the bridge, as illustrated in the following extracts from interviews.

R: I would get some cement, put one there, put one there, put one there, put one there.
I: Around each of the four feet you'd put some cement?
R: Yeah, and then it would like stay still (Peter, grade 2)

R: Cement it into the ground.
I: How would you do that?
R: It's like, dig a hole and put it in, and put cement around it (Sarah, grade 4)

Explanations of this kind occurred in a sufficient number of interviews to suggest that students may view fixing of structures into a binding material, such as concrete, as a way of improving the stability of many structures with features similar to the bridge. It would seem that the students were familiar with this approach to solving the problem, perhaps from personal experiences, conceptualizing the approach as the cement binding to the pylons of the bridge, which then "holds it tight." The effect may be seen as analogous to the action of glue binding two materials together, although an important difference is that the cement or concrete is heavy, and thus "holds it better," especially if adverse weather conditions are experienced. As Mary (grade 6) stated, "It's just more firm and it just . . . stays. It's like really heavy and it just stays there."

A variation of this idea was to screw or bolt the structure into the ground. It can be argued that this approach may have a similar conceptual basis to concreting/cementing, in that it sticks or "holds tight" the structure to the ground. The approach was often seen as being used in conjunction with concrete/cement, which supplied the necessary weight for stabilizing the bridge.

Five groups of explanations for how to make the bridge more stable emerged from the data and were labeled as *Naïve Approach, Base Anchoring Approach, Bracing (External) Approach, Bracing (Internal) Approach,* or *Other Approach* for students whose explanations were unable to be classified in any of the former. The labels for these groups represent the bases for the grouping of explanations, similar to the previous discussion for material strength. The percentage frequencies of the groups are shown in Table 2 by age level. The order of the groups, from left to right in the table, is argued, tentatively, to be representative of increasingly abstract explanations that are more complex/multiple approaches to solving the problem. Where a student's explanation was linked to two different groups, the explanation has been assigned to the more abstract group.

A *Naive approach* for making the bridge more stable may be found in Sandy's (grade 2) explanation.

I: How would I stop (the bridge) from wobbling?
R: Keep hammering in the nails until it doesn't wobble.

Table 2
Percent Frequencies of Types of Explanations with Age – Stability[#]

Year level	Naive Approach (%)	Base Anchoring Approach (%)	Bracing (External) Approach (%)	Bracing (Internal) Approach (%)	Other Approach (%)
Year 2	18.5	48.1	18.5	11.1	3.7
Year 4	5.4	46.0	37.8	5.4	5.4
Year 6	3.6	17.9	57.1	21.4	0.0

[#] Variations from 100% due to rounding.

The most common approach to this problem was, as already discussed, to place the pylons of the bridge into cement or concrete (*Base Anchoring Approach*).

Explanations that referred to the addition of an external support of some kind to stabilize the structure (e.g., external bracing or pylons) were categorized into the *Bracing (External) Approach* group. Suggested additions were external to the existing structure of the bridge and, thus, of a quite different nature to internal structural bracing. An example of this approach may be seen in Jenny's (grade 6) explanation below.

I: Is there anything we can do to improve stability?
R: Maybe you could put little things down here.
I: So, extra little legs coming down from the middle?
R: Yes, and maybe put these in cement so they won't move.

Jenny's explanation also refers to the placement of added pylons in cement in her response. Her explanation may be linked to two different groups but has been assigned to the more abstract grouping (*Bracing [External] Approach*). Some students proposed adding to the existing internal structural bracing present in the bridge (*Bracing (Internal) Approach*). Kate (grade 6), for example, when asked what changes she would make to the bridge, replied that "You might have to put more smaller triangles into these bigger ones so it's more stable."

Three students suggested solutions that implied the pylons of the bridge needed 'evening up' and were grouped as *Other* for inclusion in the table. There are clear trends in the group frequencies for explanations of stability presented in Table 2. The percent frequencies of *Naive Approach* and *Base Anchoring Approach* explanations decrease with age while the percent frequency of *Bracing (External) Approach* explanations increases with age. The results for *Bracing (Internal) Approach* do not reveal an age-related trend, which may be due, in part, to the small numbers at each age level providing such explanations. Explanations that refer to the *Base Anchoring Approach* are the most frequent for grade 2 (48.1%) and grade 4 (46.0%) students, and explanations that refer to a *Bracing [External] Approach* are the most frequent for grade 6 (57.1%) students. Based on these findings related to most frequent explanations at different age levels, we suggest that there was a change in the way students conceptualized an approach to solving the problem of stabilizing the bridge. We also suggest that adding external support to the bridge (*Bracing [External] Approach)* is a more complex, or abstract, approach than the relatively simple approach of concreting the end pylons of the bridge into the ground (*Base Anchoring Approach)*.

Discussion

The majority of students in each grade level were able to identify a material that they believed would be suitable to build a bridge on a larger scale to carry cars or pedestrians. The property of the material to which they referred, either directly or indirectly, was strength. When asked to explain their understanding of this property, students in each of the age levels often resorted to describing strength in terms of more tangible properties, such as malleability or weight.

The explanations of three grade 2 students revealed their uncertainty about material properties and how the properties of one substance would differ from other substances, for example, plastic and wood. Explanations of this kind were grouped as *Naïve* because of the students' inability to discriminate between the properties of different materials.

A second grouping (*Artifact related*) resulted from students' attempts to explain why they selected steel (or metal) for the larger bridge, but referred to the lack of strength of wood in their explanations. Arguably, if some of the students possessed an understanding of matter that involved a relationship between the type of matter and weight, a relationship noted in the science education literature (Smith, Carey, & Wiser, 1985), they might have associated the relative lightness of wood with lack of strength compared to steel. They may have seen that relationship as a reason for describing why wood should not be used, rather than being able to provide a justification that involved elaborating on a property of steel or metal. The explanations could be described as being *Artifact related* since they appear to be dependent on the nature of the material out of which the presented object is constructed.

The third group of explanations noted (*Non-artifact related*) was the students' justification for their choice of steel on the basis of a property of steel itself. The students (mainly grade 6) providing these explanations were able to think of, and evaluate, their choice of material unencumbered by the presence of a model bridge constructed out of wood at hand. Therefore, their explanations were not limited to the artifact but generalizable to other settings. Further, there was evidence that a small number of students were beginning to consider the particulate nature of materials as a way of justifying their selections of steel or concrete for the larger bridge, although it is acknowledged that such understanding was clearly emergent in nature and not fully developed.

Identifiable groups of explanations may also exist for students' understandings of stability. Gustafson et al. (1998) refer to students' ideas for making a straw tower more stable—adding a heavy base, adding feet to supports, thickening supports, adding bracing, and reinforcing joints. Although no details in their paper were provided that related the nature of the idea with age of students, there are some similarities with our findings. For example, many students in this study suggested that cementing the pylons into the ground (*Base Anchoring Approach*) could stabilize the bridge. This solution may be equated with adding a heavy base as described in the work of Gustafson et al. An increasing number of students across the age levels studied suggested that additional external bracing was required to confer even greater stability to the structure (*Bracing [External] Approach),* and others indicated that internal bracing (*Bracing [Internal] Approach)* should be added. Students' suggestions for the use of external and internal bracing as approaches to solving the problem are also in accord with the findings of Gustafson et al.

Implications and Conclusions

We conclude that there is evidence to support the conjecture that groupings of students' explanations at the different age levels are most frequent for the concept of material strength and the concept of stability. The notion of most frequent groups of explanations at different age levels is embodied in the conceptual trajectories as proposed by Driver et al. (1994). There appears to be a progression toward more abstract common explanations with increasing age for the concept of material strength. A progression in the explanations of stability is similarly apparent, albeit not definitive and relies upon certain anomalous data. The use of the model bridge at the interview may have limited some students to basing their explanations on the material out of which the model was constructed. Consequently, an important task facing researchers is to devise probes into students' understandings of technological concepts that are not linked to any particular artifact or technological process. We recognize that fulfilling such a requirement may prove to be quite challenging. Nonetheless, we suggest that it would address some important issues that have arisen from this study.

An increasing awareness of students' understandings of design and technology concepts can have an impact on the teaching and learning of design and technology in elementary schools similar to that experienced in elementary science education, which has benefited greatly from research into students' understandings of fundamental science concepts. Although more research is needed, the findings imply that commonalities and variations in students' explanations of material strength and stability may exist, and there may be an identifiable progression in the abstractness of the basis of those explanations that is age related. These implications can be taken into account in the future development of preservice and inservice teacher education programs, and the development of more appropriate design and technology curricula. The information can also inform teachers as they plan and implement technology programs, and grapple with making in-depth judgments about students' achievement of outcomes related to technology content and processes.

We consider that it is essential to continue this line of research in order to determine if similar groupings of explanations exist for other key design and technology concepts. Design and technology has a demonstrated potential to contribute to meaningful educational experiences of students. Hence, all elementary school teachers must be better informed about the design and technology concepts students acquire through engagement in technological thinking and activity. This is clearly an important concern, not only from the point of view of classroom teachers, students, and parents, but is also an increasingly important systemic consideration.

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Integrating Technology, Science, and Math at Napoleon's School for Industry, 1806-1815

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In my research on the history of teaching technology in schools, I came across the following account of the Marquis of Worcester's demonstration of the power of steam in 1663. Worcester filled a cannon three-quarters full of water, sealed its end, and then built a fire under it for 24 hours, thus "causing the cannon to explode with a loud noise" (Bossut, 1786-1787, pp. 488-9). This story was recounted by the author of one of the books listed in the curriculum of 1807 at the School of Arts and Crafts of Châlons-sur-Marne in France (hereafter school).[1] The author used Worcester's experiment to illustrate his scientific analysis of fluids and flow (hydrodynamics). Steam engines (and explosions) were undoubtedly of interest to many of the students, who spent most of their time building "real-world" artifacts in the school's shops and two or three hours per day studying drafting, math, and science in classrooms.

In the shops students made a variety of products ranging from basic hardware, files, and furniture to textile machines, scientific instruments, and clocks. From 1808 to 1815 about half of the older students manufactured caissons consisting of interchangeable parts for Napoleon's artillery—the most advanced form of manufacturing at the time. Not surprisingly, the management of some four hundred students, ranging in age from about eight to twenty years old, was a significant challenge. But added to that challenge was the goal of integrating and teaching theory and practice: practice interpreted as shopwork on marketable products according to the drawings and specifications of the director of instruction; and theory viewed as a combination of descriptive geometry, drafting, math, and science. Since that time, the school of Châlons spawned seven more Schools of Arts and Crafts which are now highly regarded schools of engineering that produce about a thousand engineers a year—the largest source of engineers in France (e. g., Ecole Nationale Supérieure d'Arts et Métiers, 1998; Day, 2001).

In this article, I intend to show that the school of Châlons forms an important chapter in the history of technology education. But why is history important for the field of technology education? In 1997 Hill and Hepburn reviewed a new book in this journal called *Changing the subject: Innovations in*

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science, mathematics and technology education. This book, they claimed, depicted technology "as a subject without a history," suggesting that "in the absence of a more developed history and description, it is difficult to assess the validity of some of the claims that the authors make concerning technology education" (p. 77). The implication here is that the lack of a history of the field contributes to ambivalence among many educators about the place of technology education, its importance, and external evaluations made about the field. In this sense, historical research has a practical side. This article focuses on a particular area of the history of technology education — the integration of technology with math and science.

The integration of technology with science and math has been the subject of research in technology education (for a summary, see LaPorte & Sanders, 1995). Daugherty and Wicklein addressed "perceived integration needs of mathematics, science, and technology education" (1993, p. 38-39). Foster (1994), in one of the most critical analyses of such integration, raised many questions and issues but did not include a historical perspective. In 1996 Childress researched the problem: "Does integrating technology, science, and mathematics improve technological problem solving?" (pp. 16-26). A study by Petrina showed that science and math occupied first and second place out of 24 content areas in terms of their alignment with technology in the content of the *Journal of Technology Education* (1998, pp. 35; 39). In a recent study on how teacher attitudes towards various aspects of teaching technology have evolved, Sanders noted that "the application of science and mathematics was essentially ignored in industrial arts education, ranking last in both 1963 and 1979, but ranked fourth (of 16 purposes) in this study. In practice, however, coordinating technology education with mathematics and science teachers is still relatively rare" (2001, p. 45). Merrill claimed that "the integration of technology, mathematics, and science education has been gaining attention . . .in recent years" (2001, p. 45). In contrast, the low profile of science and math in the new *Standards for Technological Literacy* has resulted in relatively weak guidance for such integration (International Technology Education Association [ITEA], 2000).

Integration: Physical, Conceptual, Social, and Political

This paper focuses on one of the earliest attempts to integrate technology with science and math in a school. After the French Revolution eliminated trade guilds in 1792, subsequent French governments in the 1790s introduced a variety of forms of technological education to compensate for the demise of apprenticeship systems (Artz, 1966; Léon, 1968). In this regard, France led the way in introducing instruction in technology into schools — a difficult challenge because it involved reconceptualizing, articulating, and combining heterogeneous elements in new ways. In this article I use four analytical categories: (a) physical; (b) conceptual; (c) social; and (d) political. These four analytical categories are not mutually exclusive and should thus be considered as overlapping layers, however without the hierarchy implied by layers.

Napoleon's government addressed the integration of *physical* tools at Châlons by converting a former convent to classrooms and shops, including a waterpowered sawmill. School leaders attempted to integrate *conceptual* tools such as the elements of math, science, and technology as represented in textbooks. There were various science books available, though not written specifically for a school of theory and practice. Even fewer textual resources existed for teaching the elements of technological knowledge. In fact, knowledge of the arts and crafts had only recently been systematized and presented in texts on a large scale (e.g., Diderot & d'Alembert, 1751-1772; Académie des Sciences, 1761-1789).

Social integration was just as difficult to achieve as the physical and conceptual. The school's math and science teachers had been trained in classrooms where they had observed scientific demonstrations. In contrast, the shop foremen had learned their trades as apprentices in shops or in related industrial plants such as foundries. Students differed widely in social origins, ranging from the very poor to upper middle classes. The process of integrating school personnel and students from different social positions also involved managing conflicts, as *political* power was renegotiated among groups within the school and with external power groups that included government officials in Paris, customers, and local authorities. (For an analysis of the politics of production and artifacts at the school, see Pannabecker, 2002.)

At the time the phrase "arts and crafts" or simply "arts" referred to many of the activities now referred to as technology. The school of Châlons was created during the early stages of what proved to be a long transition from craft-based societies (with apprenticeship in shops as the instructional model) to technological societies (with school-based instruction). The word "technology" was not yet used widely despite the increasing systematization of design, knowledge, tools, and production. For example, the French artillery had been the leader of interchangeable or "uniform" manufacturing since the second half of the eighteenth century (Alder, 1997). When the students of the school began making caissons, some of the tools of the artillery's system of uniform manufacturing were transferred to the school. The metric system, invented in the 1790s, was also being introduced into the school. In 1807 F.-E. Molard, director of the school shops, referred in his curriculum to a systematic approach to teaching industrial processes as they related to science and math. In the 1820s and 1830s, Molard was one of five main contributors to a 24-volume work entitled *Dictionnaire Technologique* (Francoeur et al., 1822-1835), which included two volumes of drawings of technological artifacts.

The term "mathematics" had a broader meaning than now, often including math, chemistry, and physics. The phrase "mathematical instruments" referred to a variety of artifacts ranging from drafting compasses and protractors to astronomical instruments such as sextants and reflection circles. At first all teachers of math, descriptive geometry, and scientific knowledge at the school were referred to as math teachers, but the school later began to make more distinctions in analyzing and systematizing knowledge. By the early 1820s the school had separate courses in the demonstration of machines, algebra, calculus, chemistry, physics, and descriptive geometry (ADM, 1 T 385, Annual Distribution of Prizes, 1822).

The idea of establishing such a school was linked to the Duke de la Rochefoucauld-Liancourt (hereafter Liancourt), who had established a school for military orphans from his regiment on his property at Liancourt north of Paris in the early 1780s. Liancourt, a progressive nobleman who favored liberal ideas and a constitutional monarchy, was a leader of revolutionary France during its early moderate stage. In 1792, however, he fled to England to escape the growing violence of the Revolution and then traveled for four years in the United States visiting schools, industries, and prisons. In 1799 Liancourt returned to France and in 1800, the remnants of his former school at Liancourt were moved to Compiègne, further north of Paris. In 1803, Bonaparte transformed the school into the first School of Arts and Crafts after asking his minister of the interior, Jean-Antoine Chaptal, the best known industrial chemist in France, to establish a committee and draw up regulations.[2] In 1806, Napoleon appointed Liancourt inspector of the school and soon thereafter had the school moved to Châlons (Day, 1987, 1991; Dreyfus, 1903; and La Rochefoucauld, Wolikow, & Ikni, 1980).

Physical Elements of Integration

In order to meet the goal of teaching practice, the regulations stipulated five principal shops: (1) metalwork such as blacksmithing, filing, fitting, and turning; (2) foundry; (3) carpentry and cabinetmaking for furniture and machines; (4) wood turning; and (5) wheelwright (Charmasson et al., 1987, p. 103). Since Parisian bureaucrats admitted students of a very wide range of ages, the staff sought to increase the variety of shops. When Molard drew up his “Plan of Instruction” in 1807 during the first semester at Châlons, he referred to three additional shops: a cotton-spinning shop, which was primarily for the weakest or youngest students, especially those under 12 years of age; a shop for making files; and a forging shop, separate from the fitting shop. He also proposed a ninth shop for teaching decorative patternmaking. A few years later, Molard added shops for making clocks and mathematical instruments, which required more math and science to understand their construction and uses (AN, F17 14327, “Observations préliminaires,” [from Liancourt to Bureau], 19 July 1808).

In February of 1807, the municipality of Châlons loaned to the school its collection of scientific instruments, which allowed the teachers to teach at least some of the practical aspects of science in labs (ADM, 1 T 385, Min. Int. to Bourgeois de Jessaint, 6 February 1807). A variety of instruments for the study of physics were included such as a magnet, vacuum pump, Magdeburg globe, Leyden jar, Volta pistols, and a Franklin electrical platform. Instruments for chemistry included a variety of mortars and pestles, stills, tubes, stoves, furnaces, and bellows as well as glassware (ADM, 1 T 385, “Copie de l’Inventaire,” 22 July 1818).

The specified mechanism for integrating technology with math and science was the design and fabrication of products for sale, which in the case of the instrument shop included such components as compass needles, compasses, screws, squares, and parts for cabinets or cases (AN, F12 1085, “Atelier des Instruments de Mathématiques,” December 1808). For example, a letter sent to the General Director of Mines referred to an enclosed "catalogue of astronomical instruments, of Marine, and of Geodesy" made at the school of Châlons (AN, F12 1220, Bureau to Comte Laumond, 7 January 1812). Since the school sold its instruments throughout northern France, they had to meet commercial standards and were at times inspected by some of the top scientific institutions. For example, the school sent drafting sets for inspection to the Ecole Polytechnique (hereafter Polytechnique)—a potential customer and the most elite, theoretical school in France (AN, F12 1220, “Réponse à l’Examen fait à l’Ecole Polytechnique,” 30 May 1812). The school also made instruments for ship navigation and surveying, such as reflection circles as designed by the scientist Charles Borda, with an indexed base and an eyepiece for sighting that pivoted on the base (Borda, 1787). One of the circles made at the school was sent to the Bureau of Longitudes, whose inspection then influenced the quality control of future production (AN, F12 1220, Letter from the Minister to Biot, July 16, 1808; and Report from de Rosily, Rossel, and Beautemps-Beaupré, 20 September 1814).

Conceptual Elements of Integration

The regulations of 1803 for the school stipulated the following theoretical subjects: descriptive geometry, drawing, principles of mechanics, and the nature and properties of materials. The emphasis in teaching these subjects was to be on their practical applications, the details of which were left up to the school staff (Charmasson, et al., 1987, pp. 102-104). But when Molard drew up his “Plan of Instruction” in May 1807 he divided theoretical instruction into four parts: (1) mathematics, (2) drawing, (3) French grammar, and (4) physics and chemistry applied to the arts (AN, F12 1085, "Plan of Instruction," May 14, 1807). Many of the texts that Molard listed for the school were written by teachers associated with Polytechnique but the texts varied considerably in difficulty and in their treatment of practical applications.

In mathematics, Molard included the study of arithmetic, including ordinary fractions and decimal fractions; algebra until equations of the second degree; geometry including conical sections; the application of algebra to geometry; rectilinear trigonometry; descriptive geometry and its applications to the cutting of stones, carpentry, shading, perspective, sundials; and applications of differential and integral calculus to curves. He also listed differential and integral calculus, the application of differential and integral calculus to mechanics and fluids, differential and partial equations, statics, mechanics, hydrostatics, and hydrodynamics. Some of the authors listed included content that was probably quite accessible. For example, Bossut treated all kinds of machines, including the account of the Marquis of Worcester's demonstration of the power of steam already referred to above.

Under the category of physics and chemistry applied to the arts, Molard listed the general principles of physics such as the properties of air, water, heat, light, magnetism, electricity; principles and types of measurement, including conversion to the recently invented metric system; and the practical use of thermometers, barometers, pumps, siphons, and steam engines (Haüy, 1803). For chemistry Molard referred to works that included the properties and behavior of the elements as well as compounds such as oils, acids, and oxides; natural causes that modify chemical action; and tools and equipment used by chemists to prepare materials, such as furnaces and distillation equipment (Chaptal, 1807; Fourcroy, 1801). Molard also listed a book on carpentry by J.-H. Hassenfratz, former colleague of the famous chemist Lavoisier and teacher at Polytechnique. Hassenfratz' book was practical, covering the nature and properties of woods such as specific gravity, decay, resistance, and combustibility; strength testing methods; a wide variety of saws driven by water, wind, horses, and steam power; and cost comparisons of the different methods of sawing (Hassenfratz, 1804). Finally, Molard recommended that each teacher use the *Encyclopédie* at the end of each lesson for illustrating the arts. This large compendium with its 17 volumes of text and 11 volumes of plates illustrated and described hundreds of arts and crafts as they existed in the middle of the eighteenth century (see Pannabecker, 1992, 1994, 1998).

One of the key conceptual bridges between theory and practice was descriptive geometry, as invented by Gaston Monge in the late eighteenth century. It was, and still is even today, considered the theory underlying three-dimensional representation. But it was then considered a branch of mathematics. It was not, however, very useful for generating shop drawings quickly nor was it accessible to all of the students. As for drawing, Molard included figure drawing and architectural or plan views of buildings, land plots, and machines. Since the scientists gave considerable attention to the use of drawing as a social means of controlling design and production, I consider drawing here as a bridge to social elements of integration.

Social Elements of Integration

Napoleon hoped that the school would produce a new type of leader for industry; however, there were no clear educational distinctions for training entrepreneurs, industrial engineers, shop foremen, shop managers, or skilled workers. In this regard, the school of Châlons provided a general education in technology, along with reading and writing skills. The emphasis on drawing was unusual in that it served as a means of designing and controlling production and social relationships. The regulations specifically directed the shop director to design and draw the plans for the objects to be fabricated, to show them to the students, and to guide the shop foremen, who were not allowed to make any changes in the drawings without the shop director's permission. Students were to participate in this control system of drawing, planning, and estimating by working in the drawing office as draftsmen, calculators, or writers.

Although the director of shopwork was supposed to have a pivotal role in designing and controlling all production, there were practical problems. For instance, Molard noted that the position for a "teacher of physics and chemistry applied to the arts" had not yet been filled (AN, F12 1085, "Plan of Instruction, 14 May 1807). Already at Compiègne, Liancourt had pushed the minister to establish classes in physics and chemistry that would emphasize their relationship to the arts and would be taught by the same teacher. But Molard was too busy to teach those subjects and to manage all shopwork and there was no one else at the school qualified to take his place—a social problem recognized as such by Liancourt:

> It is very natural, perhaps, that the teachers, and I speak particularly of recent graduates in mathematics, for the most part, having distinguished themselves in the best schools, have a passion for their science and the desire to push their instruction as far as they can. But this inclination—very natural in them—ends up actually being an inconvenience for the welfare of the School, which is to teach mathematics to students in their relationships with the arts, and to not create in them a dislike of the work of the arts that are the object of their institution, by a career of sciences of too high a level and too extensive in orientation. (AN F 12 1085, Liancourt's "Supplementary observations," 12 July 1806)

Both Molard and the head mathematics teacher, Philippe Rouby, were graduates of Polytechnique, but Molard was far more knowledgeable about shopwork than Rouby. Molard had gained practical experience in the artillery in Bonaparte's campaigns until 1802 and he had taught at the military school for hot air balloons. Moreover, his older brother, C.-P. Molard, was director of the Conservatory of Arts and Crafts in Paris—the foremost institution in France for the advancement of technology (Michaud, Michaud, & Desplaces, 1854-1865, pp. 517-519).

In 1807 Rouby wrote to the minister requesting permission to work in the school shops, which suggested that he was finally responding to Liancourt's pressure to take a more practical approach in his teaching (AN, F12 1085, Liancourt's "Supplementary Observations," 12 July 1806). Rouby wrote that in view of the goal of teaching to students the mathematics "necessary to the calculation and construction of machines, and to have them perform frequent applications in order to make the theory of the [mechanical] arts as familiar to them as practice, he [Philippe Rouby] has for several years now believed that he should work at the manual tasks necessary to guide himself in the applications of the Theory that he has to teach to the students" (AN, F12 1084, Philippe Rouby to Min. Int., no date, but received by the Ministry on 13 January 1807).

But why did Rouby not simply ask the school's director Joseph Labâte, Liancourt, or Molard for permission to work in the shops? Not long before moving to Châlons, most of the teachers signed a petition to the minister protesting the lack of vacation time as in other schools and requesting a month of vacation (AN, F12 1085, Letter from teachers to Min. Int., 8 August 1806). Although they admitted that they had been told that the school of Châlons was designed to be a different type of school, with little or no vacation periods, they did not agree with the lack of vacations. Rouby's signature is among the dozen and a half names at the bottom of the letter. The next year most of the same teachers protested the elimination of Thursday afternoon holidays typical in other secondary schools (AN, F12 1085, Letter from teachers to Min. Int., 19 June 1807). This controversy continued for a few more years, thus underlining differences in social attitudes between traditional teachers and shop foremen. Later two math teachers claimed that more teachers would have signed the protest letter but instead agreed to write to Liancourt, in his capacity as inspector, "out of fear of being considered informers" (AN, F12 1085, Aboilard and Odet to Min. Int., 14 January 1809). Liancourt responded in a scathing letter in which he severely criticized the teachers for their insubordination and its effects on the students:

> . . . I will repeat what I have already told you many times, that at the School of Arts theoretical instruction is only subsidiary to industrial instruction; that there is absolutely no reason for you to continue to liken this School to the *lycées* or other purely theoretical institutions; that the very small number of hours that your classroom teaching takes of your time leaves you with plenty of time for preparing your lessons and reviewing your students' compositions…(AN F12 1085, Letter from Liancourt, January 17, 1809)

Indeed, the high social status of theory would have made it especially difficult for math teachers to accept that practical instruction in the shops took precedence over theoretical instruction.

But these were not the only social conflicts. Teachers taught in classrooms separate from the shops. Sometimes the teachers excused the best students from shopwork so that they could progress faster in mathematics and the shop foremen excused students from classwork so that they could contribute more to production. Rouby also had a longstanding feud with Arnauld, the assistant director of shopwork, who at Compiègne had accused Rouby of attempting to assassinate him by shooting at him from his window (AN, F12 1130, Rouby to Min. Int., 29 July 1806). In light of this feud and knowing full well the extent of the autocratic rule under Napoleon, perhaps Rouby wanted to document his support of the goals of the school. Indeed, perhaps he was beginning to accept that the goal of teaching theory as it related to practice would not go away by simply placing more emphasis on mathematics.

In any case, Rouby's letter confirms the difficulty that teachers without much practical experience had in integrating math and science with practice. But Molard and the shop foremen also had their reasons for not focusing on the integration of technology, math, and science. The Bureau in Paris was exerting tremendous pressure on them to increase production and income, thus pitting production against instruction (AN, F17 14327, “Règlements (projets),” 1807-1812). Liancourt, who had long been supportive of the emphasis on shopwork and the generation of income, favored pay incentives to students to motivate them and thereby render them more compliant in order to increase production. The Bureau’s pressure to produce income, Liancourt’s emphasis on production, and the Bureau’s failure to provide appropriate markets distracted Molard from focusing more energy on innovative ways to integrate math, science, and technology. The importance of these social problems cannot be overstated. In fact, a later example in the history of nineteenth century United States confirms this very problem. In citing the “Prospectus” of 1879 of the Manual Training School of Washington University, Calvin M. Woodward, a leading figure in the promotion of manual training in the United States, drew the following conclusion: “A shop which manufactures for the market, and expects a revenue from the sale of its products, is necessarily confined to salable work, and a systematic and progressive series of lessons is impossible” (Woodward, 1887, p. 6).

The Politics of Integration

The disputes between teachers and administrators over holidays and between teachers and shop foremen over instructional priorities were also political in that they concerned the distribution of power within a hierarchy. These problems were compounded by social structures external to the school. For example, Liancourt complained of the lack of teachers trained to teach integration of theory and practice: “I don’t know if there are in France a satisfactory number of authors who have treated the sciences purely in relationship to the arts” (AN, F12 1085, Liancourt’s “Observations Supplémentaires,” 12 July 1806). As a result, Molard had considerable authority, and administrators in Paris worried about the extent of his power. The regulations of 1803 provided for a shop director, but no director of instruction to formally promote integration, an arrangement that facilitated the tendency of the bureaucrats in Paris to exploit the system of production over instruction (AN, F17 14327, Lausel and Costaz to Min. Int., 3 July 1807). And by keeping up pressure on Molard to increase sales and income, the Bureau kept Molard busy identifying markets and coordinating sales of products (ADM, 1 T 2233*, “Conseil des ateliers,” 1 July 1808–16 February 1815). Disputes revealed that the bureaucrats opposed an integration of the two functions of coordinating both theoretical and practical instruction in one person (Molard), an arrangement that they finally approved reluctantly due to the persistence of Liancourt (AN F 12 1085, Liancourt’s "Supplementary observations," 12 July 1806).

Politics affected students as well. For example, the regulations of the school promoted a particular political view of power in that students were to be organized into military-style companies supervised by a student sergeant and two corporals, selected according to their experience, instruction, and ability (Charmasson et al., 1987, pp. 103-104). Students were also supposed to receive pay for their work according to a sliding scale linked to their rank. In this way the Napoleonic regime promoted a meritocracy that contrasted with the emphasis of Old Regime France on power defined by aristocratic birth and privilege. Not surprisingly, there existed a wide range of attitudes among students. This situation was exacerbated by the fact that the bureaucrats in Paris flooded the school with an excess of students, with little regard to age and abilities. Parents who were well off financially sought special privileges for their sons. Labâte also reinforced a dualism of theory and practice. At one extreme, Labâte exempted two students from shopwork for a month in order that they could prepare for the entrance exams for the Ecole Polytechnique (AN, F12 1084, Labâte to Min. Int., 13 November 1807). On the other hand, he excused some students from class with only a minimal introduction to math and science. Before the move to Châlons, Labâte reported that about 40 students (about 10% of the total) had completely wasted their time in the classwork and had learned nothing, either by lack of ability or willingness. All sorts of punishment had failed to improve the situation and Labâte finally proposed that they spend the entire day in the shops except for an hour and a half per day of writing, reading, and the simplest calculations (AN, F12 1084, Labâte to Min. Int., 4 Fructidor year 12 [1804]).

Teachers and shop foremen also contributed to polarization. Some of the students who lacked ability or interest in math would hassle the teachers, who then excused them from classes. Some of those teachers then failed to notify the principal of absences and some of the shop foremen were willing to accept the additional students to increase production. Liancourt noted that the shop foremen, “believing within themselves, like all ignorant persons, that instruction in the sciences is useless, and far from encouraging their students, are disposed to discourage them and even create in them a dislike [of the sciences]” (AN F 12 1085, "Supplementary Observations," July 12, 1806). Nevertheless, bureaucrats in Paris complained frequently of instability at the school, but did little to optimize the educational climate of the school; worse, they pushed for maximum production through specialization and repetition.

Indeed, social and political conflicts also existed at the highest levels of French government. In January 1808 the minister of the interior proposed to Napoleon to eliminate the school due to its instability and failure to produce income commensurate with the ministry’s expectations. Napoleon refused to hear of it and immediately made a counterproposal that the school manufacture artillery equipment, which triggered student involvement in interchangeable manufacturing (Napoléon, 1864, p. 337). Caisson production had both negative and positive aspects. Students were exposed to the most up-to-date style of manufacturing in existence, involving the use of physical and conceptual tools: standardized drawings, specifications, models, and limited use of jigs and fixtures. The demands on Molard for managing drawings were reduced because the school simply adopted the drawings of the artillery. Income from production increased and pressure from the bureaucrats was somewhat relieved. But students who specialized lost in terms of the breadth of their learning. They eventually achieved acceptable standards of uniformity, but only after a long series of disputes with Paris and the artillery over uniformity. These disputes, often expressed as technical disagreements over uniformity, were in fact linked to political issues such as the artillery's preference for controlling production in its own shops.

Conclusion

Historical studies expand the research discourse of a field by introducing a broader set of questions. For example, Merrill emphasized the growth of interest in the integration of technology, mathematics, and science education in recent years (2001, pp. 45; 47; 58). But is Merrill implying that we are facing a new idea or challenge, or rather a renewed interest that is part of a cyclical pattern of waxing and waning interest over the last two centuries? If there has been such a cycle, does its behavior correspond to other technological, educational, social, or political trends? Do governments promote the integration of technology with math and science in hopes of spurring national economic development? What are the politics of integrating technology with math and science? How are politics embedded in educational programs, their physical artifacts, conceptual tools, and social forms of instruction?

In addition to stimulating these broader questions, historical narratives and analyses recall and reinterpret specific stories of the past and in so doing redefine the heritage of an evolving field. In the case of the school of Châlons, for example, historical documents suggest that manufacturing caissons was an anomaly in the school's history. The school eventually did supply the artillery with caissons of acceptable uniformity, but the demise of Napoleon in 1815 brought that experience to an abrupt halt. The school did not continue interchangeable manufacturing or military production, but it did continue to pursue industrial precision and the integration of math, science, and technology. Eventually the curriculum of the school influenced programs in the United States, thus raising broader questions about how and why educational programs are transferred across international boundaries. More extensive study of the history of the integration of math, science, and technology would provide insights into how technological knowledge and practice have evolved along with, and distinct from, math and science. Historical study is therefore practical in that it expands the context in which today's educational efforts are assessed by revealing how physical, conceptual, social, and political values have influenced the integration of technology with math and science in the past.

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Endnotes

[1] The author gratefully acknowledges the assistance of the staff of the Archives Nationales (Paris, France) = AN; and the Archives Départementales de la Marne (Châlons-en-Champagne, formerly Châlons-sur-Marne) = ADM. References to archival documents include four components: (a) archive (e.g., AN); (b) series and carton number (e.g., F12 1084); (c) brief title or description of the document; and (d) date of document. In these references, the Ministry of the Interior is abbreviated "Min. Int."; the Bureau of Arts and Manufactures is abbreviated "Bureau". The Ministry of the Interior managed the school through the Bureau of Arts and Manufactures. For an excellent reference work and guide to the National Archives of France for the history of technical education in France, see Charmasson, Lelorrain, & Ripa (1987). Translations are my own unless otherwise noted.

[2]The original regulations in 61 articles for the school were promulgated on 6 ventôse year 11 and reproduced in Charmasson, Lelorrain, & Ripa (1987, pp. 102-108). At the time of their promulgation, the Revolutionary calendar was still in effect, hence the date 6 ventôse year 11, which corresponds to 25 February 1803.

Biotechnology Education: A Multiple Instructional Strategies Approach

Trey Dunham, John Wells, and Karissa White

The creation of an environment in which students are best able to learn is of primary concern for any teacher. Regardless of content, good instructors desire to meet the educational needs of their students. While increased understanding and comprehension is always desired, teachers presented with new curriculua or content areas are faced with the challenge of delivering and learning the new material, as well as teaching in the most effective manner. Teachers do not often have the time to consider and reflect on the appropriateness of a new curriculum, its content and structure, or instructional strategies for delivery. A call for the inclusion of biotechnology in technology education curricula (ITEA, 2000) raised these challenges for many technology education instructors. Questions about why and how to integrate biotechnology into existing programs will become more prominent in the near future: *Why should biotechnology be included in technology education? What is biotechnology? How is the study of biotechnology structured?* and *What are some appropriate strategies for teaching biotechnology?* This paper will provide a brief rationale for the inclusion of biotechnology in technology education, a definition of biotechnology, a structure of the content area, and an overview of pertinent learning theory. Most of the discussion focuses on an approach to biotechnology instruction that employs elements of the teaching and learning principles found in behavioral, cognitive, and constructivist theories.

Biotechnology: Rationale for Inclusion

Few fields in the modern world have advances as rapid as those that have taken place in biotechnology. Since determining the structure of DNA in the mid-1950s advances in cellular biology, medicine, genetic engineering, and bioprocessing have emerged so quickly and on such a large scale that educators have been hard-pressed to keep up with new developments. From an educational standpoint, *Project 2061* of the *Science for All Americans* initiative (SFAA, 1989) determined a need for reform in science, mathematics, and technology in order to better reflect the rapidly changing world of science and technology. Biotechnology education was specifically identified for inclusion in science,

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mathematics, and technology curricula. Within the field of technology education, biotechnology has slowly emerged as a legitimate area of study.

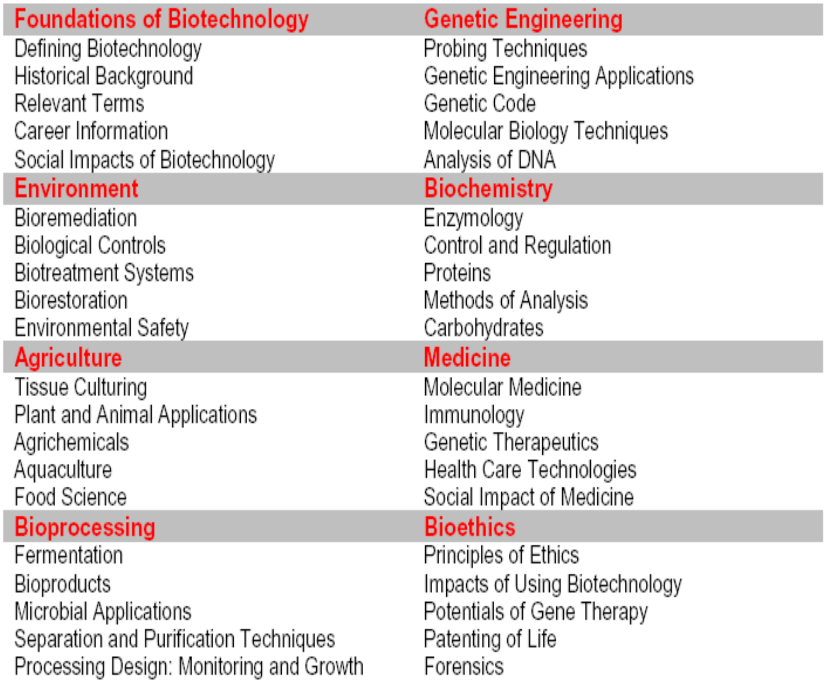
Savage and Sterry (1991) asserted that biotechnology should be included as a content organizer in the technology education framework alongside communication, production, and transportation. Five years later, the *Technology for All Americans* project (ITEA, 1996) included biological systems as part of its structure for the study of technology. Currently, biotechnology is included among the standards for technological literacy in the United States and abroad (ITEA, 2000; NZME, 1995).

Biotechnology: Definition and Structure

Without an accepted definition of biotechnology, it is difficult to distinguish what is and what is not biotechnology, and any attempt to develop biotechnology curricula would be confounded by a lack of sufficient guidelines (Wells, 1995). The Office of Technology Assessment (OTA, 1988, 1991) defined biotechnology as *any technique that uses living organisms (or parts of organisms) to make or modify products, to improve plants or animals, or to develop microorganisms for specific purposes.* Other federal agencies, such as the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET, 1992, 1993) and the Biotechnology Research Subcommittee (BRS, 1995) adopted this definition in an effort to address audiences ranging across government, industry, and academia. The *Technology for All Americans* project (ITEA, 1996) employed this definition of biotechnology as well in its *Rationale and Structure for the Study of Technology.* By accepting a common definition, disparate communities can enter the “collaborative venture that is biotechnology research and development” (BRS, 1995, p.3).

From a technology education standpoint it is equally important that an agreed upon definition be established. “Without the profession’s adoption of [an] established definition there will continue to be misconceptions surrounding [biotechnology] and persistent difficulty with its inclusion into technology education programs” (Wells, 1995, p.12). As a result ITEA (2000), in its *Standards for Technological Literacy*, followed OTA (1988, 1991) and FCCSET (1992, 1993) in defining biotechnology. This definition, being widely accepted across government, industry, academic institutions, and within technology education itself, serves as an appropriate foundation for biotechnology education.

With a clear definition established, biotechnology’s “position within the technology education curriculum is more evident, and instructors will find points of inclusion they recognize and can incorporate” (Wells, 1995, p.12). Though having accepted a definition, the profession continues to work toward formulating an overall structure that outlines the content of biotechnology. While there have been a few efforts to determine appropriate content organizers for biotechnology (Brown, Kemp, & Hall, 1998; Savage & Sterry, 1991), arguably the most inclusive are the eight Knowledge Areas (Wells, 1994)—foundations of biotechnology, environment, agriculture, bioprocessing, genetic engineering, biochemistry, medicine, and bioethics—established in the taxonometric structure for biotechnology. Subdivisions within the eight Knowledge Areas further specify the content dimensions (see Figure 1). The *Technology Education Biotechnology Curriculum* (Wells, White, & Dunham, 2000) is based on this taxonomy, and the biotechnology activities presented in this paper are part of that curriculum.



Foundations of Biotechnology	**Genetic Engineering**
Defining Biotechnology	Probing Techniques
Historical Background	Genetic Engineering Applications
Relevant Terms	Genetic Code
Career Information	Molecular Biology Techniques
Social Impacts of Biotechnology	Analysis of DNA
Environment	**Biochemistry**
Bioremediation	Enzymology
Biological Controls	Control and Regulation
Biotreatment Systems	Proteins
Biorestoration	Methods of Analysis
Environmental Safety	Carbohydrates
Agriculture	**Medicine**
Tissue Culturing	Molecular Medicine
Plant and Animal Applications	Immunology
Agrichemicals	Genetic Therapeutics
Aquaculture	Health Care Technologies
Food Science	Social Impact of Medicine
Bioprocessing	**Bioethics**
Fermentation	Principles of Ethics
Bioproducts	Impacts of Using Biotechnology
Microbial Applications	Potentials of Gene Therapy
Separation and Purification Techniques	Patenting of Life
Processing Design: Monitoring and Growth	Forensics

Figure 1. Taxonomy for biotechnology education (Wells, 1994)

Learning Theory in Technology Education

Technology education, like all disciplines, has ebbed and flowed with the changing tides of learning theory. And as is often the case, residue from the previous tide remains behind, mixing with new methods of teaching. Three influences in technology education have been the behavioral, cognitive, and constructivist philosophies. While all of them generate some criticism and praise from academics and researchers, it is apparent that technology education has been shaped by all three and retains characteristics of each one.

Behaviorism.

Behaviorism has deep-rooted connections with technology education's approach to instruction. In general, within the United States, teachers are the locus of control in the classroom. Not only are instructors central to classroom activity, they out-talk students by a ratio of three-to-one, with a vast majority of the instruction originating from the teacher (Goodlad, 1993). Historically this instructional approach has been similar within technology education. Petrina (1993, 1994) argued that the popular modular approaches to technology education are behavioral in nature. While these methods promote stability and certainty with respect to outcomes, "there is little discussion and few opportunities for students to contribute their own feelings, ideas, or concerns during the course of instruction" (DeMiranda & Folkestad, 2000, p.2). In addition, behavioral philosophy asserts the acquisition of competencies, and standards of performance serve as a measure of learning (Spurgeon & Moore, 1997). Technology education, with the advent of the *Standards for Technological Literacy* (ITEA, 2000), has adopted this philosophy as well.

Cognition

Cognitive learning theory also has close connections with technology education. While Lewis, Petrina, and Hill (1998) pointed out that problem-solving is a "process or 'cognitive' skill" (p.3), both Savage and Sterry (1990) and Pucel (1992) argued that it is a central aspect of technology education. This suggests that a cognitive approach to learning, as manifested in the problem-solving tradition of technology education, is a core value of educational theory in technology education (Lewis, Petrina, and Hill, 1998).

Constructivism

Constructivist theory frames learning as an active and continuous process whereby the learner takes information from the environment, especially social contexts, and constructs personal interpretations and assigns meaning based on prior knowledge and experience (Glasersfeld, 1995). Learning takes place as students discuss and share problems and solutions in meaningful contexts, through collaboration, by developing unique solutions and participating in thoughtful reflection (Jonassen, 1994). Many suggest that these strategies are appropriate for technology education, although underemployed (DeMiranda & Folkestad, 2000; Minstrell, 1984; Pea and Gomez, 1993).

This brief overview presented on learning theory in technology education indicates the degree to which their influence has, and continues to shape the teaching strategies of technology educators. Arguably, for the technology education content and typical instructional environments, a teaching approach that incorporates a blend of elements from these theories will be most successful in promoting knowledge acquisition. Biotechnology, like the other content areas of technology education, is naturally interdisciplinary and lends itself to a blended approach of behavioral, cognitive, and constructivist principles in the design of instruction. It was from this premise that the *Technology Education*

Biotechnology Curriculum (TEBC), including the two activities selected for discussion in this paper, was developed.

Biotechnology: A Multiple Instructional Strategies Approach

Important to the delivery of biotechnology content is a pedagogical foundation built on solid learning and instructional theory. Biotechnology content, as part of the technology education curriculum, can be delivered employing teaching strategies common across technology education content areas that utilize instructional approaches based on behavioral, cognitive, and constructivist philosophy (ITEA, 2000). The remainder of this paper looks at two biotechnology activities from the TEBC (Wells, et al., 2000), and discusses the blend of learning theory that supports the delivery of biotechnology content in the technology education classroom. The first example, taken from the Agriculture Knowledge Area, examines the use of photobioreactors in the production of alternative, non-chemical fertilizers. The second activity, taken from the Bioethics Knowledge Area, probes bioethical issues surrounding the use of the growth hormone *bovine somatotropin* (BST) in milk production. The delivery of these two activities can be shown to rest on solid pedagogical footing by recognizing the behavioral, cognitive and constructivist principles purposefully designed into the teaching and learning strategies.

Behavioral Elements

Students rely on teachers for information at the beginning of any learning activity. From a behavioral perspective, teachers manipulate and orient the learning environment depending on the desired outcome (Skinner, 1971). A teacher directs student learning by establishing classroom conditions: the context of the activity, the student task, the expected outcomes, and the resources and information available to the student.

Setting the Context. Typically, it is the teacher who sets the context for an instructional activity. Depending on the circumstances, teachers determine what type of activity will be appropriate in meeting the instructional needs of their students. In setting the context for the photobioreactor activity, teachers alert students to the commercial use of photobioreactors for growing algae and other green pigmented cell lines. Part of this context is also the awareness that algae are useful as an alternative to chemical fertilizers, and preferable because of their low impact on the environment. In the bioethics activity the teacher sets the context by informing students that BST is a growth hormone used in the dairy industry to increase milk productivity in cows. This is a bioethical concern because the use of hormones raises issues of public safety (Wells, et al., 2000).

From a behavioral standpoint, the context for both activities is directed and established by the teacher, who is free to vary that context in accordance with local issues or conditions. For example, teachers may adopt a local perspective where photobioreactors are used in food production, or they may choose to capitalize on a situation where growth hormones are used by a local industry to increase livestock production. In any case, it is the teacher that sets the context and provides for the student the setting in which learning is to take place.

Stating the Challenge. It is within the teacher-set context that the student activity will occur. In the photobioreactor activity the student is given the task of designing and building a photobioreactor that grows algae for use as an alternative fertilizer on food crops. Although algae are used in a variety of ways, this challenge directs the student to use it as an environmentally-friendly fertilizer (see Appendix A). The exact outcome of the activity will vary from teacher to teacher: one could require a model, prototype, or simply a drawing of the photobioreactor system as a demonstration of acquired knowledge. Similarly, the bioethics activity requires that students participate in a mock courtroom setting where they debate the use of BST in the milk industry (see Appendix B). Again, outcomes will vary: a courtroom debate with members of the class taking sides, or a poster display that highlights arguments from both sides of the issue. By presenting a challenge or problem to be solved, the instructor dictates the tasks to be performed by the class and the ways in which that challenge is to be fulfilled.

Establishing Evaluation. The evaluation element in these biotechnology activities also serves to direct student learning. A set of evaluation questions, given in conjunction with the context and challenge, alerts students of teacher expectations and assists in the initiation of the activity. These questions direct students toward research information needed to complete the problem, purposefully guiding them toward an understanding of the biotechnology processes involved. In these biotechnology activities students are asked to learn about both the biological process and its technological application. The evaluation questions, therefore, ask students about the type of organism (or part of an organism) that is used, as well as its life and growth requirements. In the photobioreactor activity, students are asked questions related to how the system grows algae and distributes it directly to the field: How does the system work? What other photobioreactor techniques are possible? and How does the system meet the life and growth requirements of the algae? (see Appendix C). The BST evaluation questions guide the class in determining the biological and technological information necessary to defend a position regarding such questions as: What organisms (or parts of organisms) are involved in BST biotechnology? How are these organisms used to increase milk production? and What are the advantages and disadvantages of BST use? (see Appendix B).

Providing Information. In providing specific information about the biological and technological processes, the teacher establishes a more exact context for the class and the biotechnology activity. The photobioreactor activity explores the use of algae as an alternative fertilizer. Students can be told that they will be using Spirulina, an algae that grows rapidly and has a high concentration of nutrients. Like all organisms Spirulina grows best when certain conditions such as light, nutrients, pH, and CO_2, are optimized. A photobioreactor maximizes these conditions through its design: the use of clear plastic tubing for efficient and volumetric distribution of light; efficient delivery of light from the source to the algae; air lift pumps to keep the algae in suspension; mechanism for CO_2 and O_2 exchange; pH and growth sensors.

By setting the context and challenge, providing targeted evaluation questions, and offering pertinent information to direct the student towards a desired outcome (a biotechnical solution), the instructor is employing behavioral instructional strategies. However, instead of providing *all* the information, students can also research and discover this information independently. From a cognitive perspective it is not always necessary, or even desirable, that the teacher serve as the sole source of knowledge for the student. Biotechnology activities, given the interdisciplinary nature of the topic, provide a rich setting for student engagement in problem solving, investigation, and discovery—a hallmark of the cognitive orientation (Bruner, 1965). As students research and discover on their own the information needed to solve the biotechnology challenge, they move from a directed behavioral context to one of cognitive structuring.

Cognitive Elements

Once placed within a context and given adequate direction, the locus of learning in these biotechnology activities shifts to the student. Cognitive theory recognizes that "the human mind is not simply a passive exchange-terminal system where stimuli arrive and the appropriate responses leave. Rather, the thinking person interprets sensations and gives meaning to the events that impinge upon his [or her] consciousness" (Grippin & Peters, 1984, p.70). Given a context, a problem, and appropriate background information, the learner is freed to arrange these ingredients in various ways until a solution is found (Hergenhahn, 1988). Bruner (1965) emphasized that learning occurs through this type of discovery. Encouraged to explore, students rearrange and transform evidence in such a way that new insights are gained. The internal cognitive structure of the student is changed as a result of interacting with the environment and being exposed to an increasing number of experiences (Piaget, 1966). As students investigate, gather, and reassemble information, learning takes place. "Learning involves the [cognitive] reorganization of experiences in order to make sense of stimuli from the environment" (Merriam & Caffarella, 1999, p.254). After the teacher has set the parameters for the biotechnology activities, the focus shifts to the student who must then begin to reorganize, investigate, and solve the problem. Carefully designed introductory activities and problem-solving methodologies were two instructional strategies used in the biotechnology activities to set the cognitive stage from which a photobioreactor or bioethics solution might be conceived.

Introductory Activities. During the presentation of new biotechnology concepts, a teacher may use introductory activities to frame *advanced organizers*, which prepare students for future learning (Ausubel, 1968). By examining photobioreactors already in use students are provided a basic understanding of what photobioreactors are and their various applications. This exposure creates a new awareness from which students are able to draw on as they complete their own challenge. Two good examples of photobioreactors in use can be found on the Internet. The BioCoil Project (Cascade High School, 1995) uses algae grown in a photobioreactor to clean community wastewater. The BioFence (Biosynthesis, 2000) photobioreactor grows algae as a food supplement. A virtual tour of these two websites can provide the class with an understanding of how photobioreactors work, how they are designed, and what they produce, while concurrently presenting them with an advanced cognitive framework.

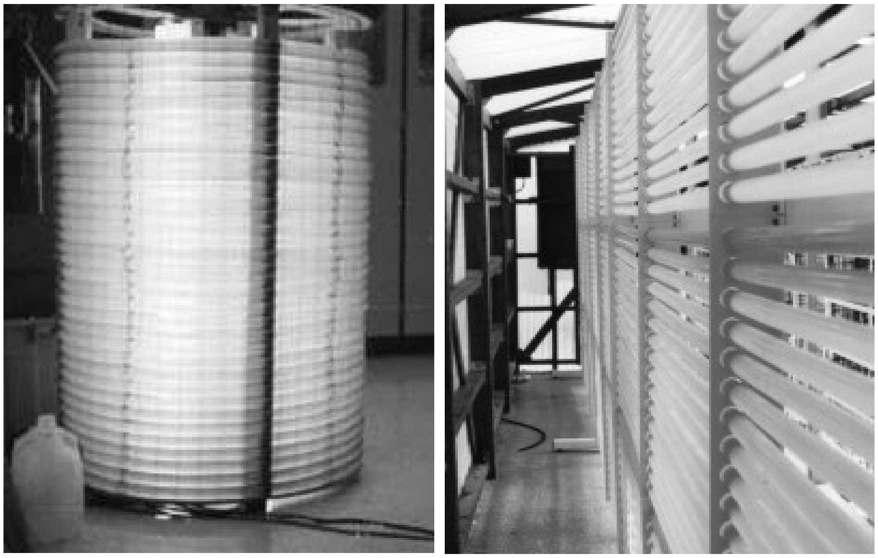


Figure 2. BioCoil BioFence. The BioCoil is a photobioreactor used to clean wastewater. The BioFence grows algae as a good supplement.

In debating the use of BST, students will engage in ethical decision-making processes. Introductory activities about how to make an ethical decision can equip a class with a cognitive structure within which the bioethical debate over BST can be understood. The following introductory activity investigates the ways in which one's perspective of an issue may affect individual opinions or decisions:

1. Place an irregularly shaped box in the center of the room. The sides of the box should be covered in varied shapes of different color and size.
2. Ask students to describe the box from their point of view. *Do they agree with the description of the box given by others in the class? Why or why not? What are the factors that affect how one describes the box?* (Wells, et al, 2000).

This activity develops the idea that opinions, including bioethical opinions, depend upon one's perspective or point of view. To further develop this idea, a follow-on activity may explore the "ethical" issue of breakfast. The teacher assigns a "value" to student groups: taste, time, expense. The student groups must then choose what they will have for breakfast based on their assigned value. These two introductory activities promote a decision-making process that emphasizes points of view and/or personal values, while also offering a framework from which the BST bioethical issue can be discussed and explored. As students research and develop arguments for or against the use of BST they will have in place a cognitive structure that helps them to think about the BST issue from an ethical perspective.

Problem-solving Methodology. A problem-solving methodology is a second cognitive element that can be employed in biotechnology education. Familiar to most in technology education, problem-solving often consists of four phases: design, production, evaluation, and presentation. A hallmark of the cognitive learning orientation, the problem-solving methodology focuses on the internal mental processes of the student (Merriam & Caffarella, 1999). Knowles (1984) claims that the problem-solving approach emphasizes the discovery approach of Bruner (1965) by involving three almost simultaneous processes:

(1) acquisition of new information;
(2) transformation, or the process of manipulating knowledge to make it fit new tasks; and
(3) evaluation, or checking whether the way we have manipulated information is adequate to the task. (Knowles, 1984, p.25)

To complete the photobioreactor challenge students must acquire new information, transform that information into a solution, and then evaluate the appropriateness of their system in addressing the specific details of the problem. In the design phase, students gather the following information: *What are the components of a photobioreactor system? For whom is the system being designed? Where is the system to be located? What types of photobioreactors are possible?* This information is transformed into multiple design ideas and checked for adequacy with respect to the challenge. In the production phase, students gather materials and transform them, according to the design, into a new, unique photobioreactor. The presentation requires that students check the adequacy of their biotechnology solution by revisiting the steps they followed and the evaluation questions given at the outset of the activity.

The BST activity, while addressing a different type of biotechnology problem, can nonetheless employ the problem-solving process. Teams gather information that illuminates the issue: *What are the impacts of BST on food safety? What are the economic impacts of BST? How does the use of BST affect large or small farms?* This information is transformed into an argument for or against the use of BST in milk production. Displays, props, and opening and closing arguments are constructed for use in the courtroom scenario. Each group evaluates the effectiveness and adequacy of their arguments in support of their position before participating in the debate.

The cognitive orientation to learning holds that both advance organizers and internal mental processes, such as problem-solving, are important agents of learning (Ausubel, 1967; Bruner, 1965). While the introductory activities and problem-solving methodology provide a means to acquire, transform, and evaluate new knowledge, students will themselves construct new knowledge as they investigate biotechnology. As the class completes these biotechnology activities they will make sense of their experience through their interaction with others in this context.

Constructivist Elements

During the process of completing the photobioreactor and BST activities, students generate many products. These products can be a physical artifact, an accumulation of knowledge, or a new understanding of the world in which they live. Constructivism holds that a key feature of learning is *constructed meaning*, where one's cognitive structures are adapted to the physical environment; "it is how people make sense of their experience" (Merriam & Caffarella, 1999, p.261). Social constructivists maintain that learning occurs "when individuals engage socially in talk and in activity about shared problems or tasks" (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p.7). Learning takes place as students discuss and share problems and solutions. Several instructional strategies associated with a constructivist learning environment—meaningful contexts, collaboration, unique solutions, and thoughtful reflection (Jonassen, 1994)—can be incorporated into the photobioreactor and BST activities.

Meaningful Contexts. A major characteristic of the constructivist learning environment is the presence of authentic tasks set within a meaningful environment (Jonassen, 1994). The photobioreactor and BST activities are authentic for several reasons. First, they are part of the real world in which students live, and present issues that have significant impact on socio-cultural structures. Second, students are exposed to, and interact with, fertilizers and hormones every day by way of the food they eat and the environments in which they live. Third, students are likely to have had personal experiences related to the issues addressed in these activities: fertilizing their lawns and drinking milk. Because these activities are authentic and occur as part of the students' real world, the learning context they create promotes individual meaning and positively affects student engagement and learning.

Collaboration. As a part of a team, students interact, discuss, investigate, and create unique solutions to the biotechnology problem. The photobioreactor and BST activities encourage multiple points of view and an environment where unique learning experiences can occur. Teams are expected to discuss, negotiate, and collaborate as they build a novel photobioreactor that meets the specific needs of their scenario. Similarly, students work together to build an argument for or against the use of BST. The role of the teacher in these instructional environments is not to dictate solutions or answers, but rather to participate in the discussion by facilitating and negotiating the new meanings and knowledge being constructed by the student teams. It is the social interaction and negotiation, as opposed to 'correct' answers, that generate meaning and foster learning in the constructivist environment (Jonassen, 1994; Driver et al, 1994). Students design and construct unique solutions together while the instructor stimulates and encourages the class to look for solutions that have meaning for them.

As mentioned, such collaboration in the biotechnology activity takes place within the context of a team. Students research, design, construct, and evaluate either a photobioreactor or BST argument as a group. Each member is assigned a role with team responsibilities that contribute to the final solution: the *research analyst* leads the data-gathering portion of the activity; the *design manager* facilitates the discussion surrounding the development of a solution; the *materials specialist* initiates the construction of the prototype and presentation materials; *quality control* guides the group's analysis of their solution and its adequacy to the challenge (Wells, et al., 2000).

Unique Solutions. Knowledge construction, rather than knowledge reproduction, is another characteristic of the constructivist classroom (Jonassen, 1994). This learning strategy is well suited for biotechnology in that these activities encourage unique solutions to each challenge. In the photobioreactor activity two teams may take different approaches to the same problem: one could decide to use a coil array, while the second might choose the 'fence' arrangement in which to grow algae (see Figure 2). Teams addressing the BST problem could choose from any number of perspectives from which to present their case: economic, social, ethical, or medical, depending on their own experience and understanding of the problem. While each solution addresses a single problem, they allow for the experiences, interpretation, and knowledge of each member of the group. Originality in problem-solving demonstrates that students have internalized key concepts, while the multiple representations of reality generated by these activities avoid oversimplification and represent the true complexity of the world.

Thoughtful Reflection. As teams work toward completion of the photobioreactor or BST activity, they continually engage in a process of evaluation by reflecting on the solution at various times during the problem-solving process — formative evaluation. Thoughtful reflection on experience is an important component of the constructivist learning environment (Jonassen, 1994). Formal presentation is the preferred assessment tool for the biotechnology activities because it affords teams the opportunity to reflect on the context, challenge, biotechnology processes, and final solution. As the presentation is assembled, each team is given the opportunity to revisit the context, challenge, design, and construction processes in order to assess the adequacy of their solution in addressing the challenge. Ultimately, final presentations exemplify the students' acquisition of knowledge resulting from the learning experience.

Conclusions

The teaching of biotechnology in the technology education classroom can be accomplished using a variety of instructional strategies that effectively deliver content and engage students in real world problems. Biotechnology activities such as the two presented in this paper demonstrate a blend of behavioral, cognitive, and constructivist learning theories. A teacher directs student learning by establishing classroom conditions: the context of the activity, the student task, the expected outcomes, and the resources and information available to the student. Introductory activities and a problem-solving methodology are two instructional strategies that shape the cognitive structure in which a photobioreactor or bioethics solution can be generated. The photobioreactor and BST activities both utilize instructional strategies that promote constructivist learning environments—meaningful contexts, collaboration, unique solutions, and thoughtful reflection. This combined behavioral, cognitive, and constructivist approach to teaching biotechnology provides a structure and strategy that reflect the instructional philosophy and traditional approach to content within the technology education profession.

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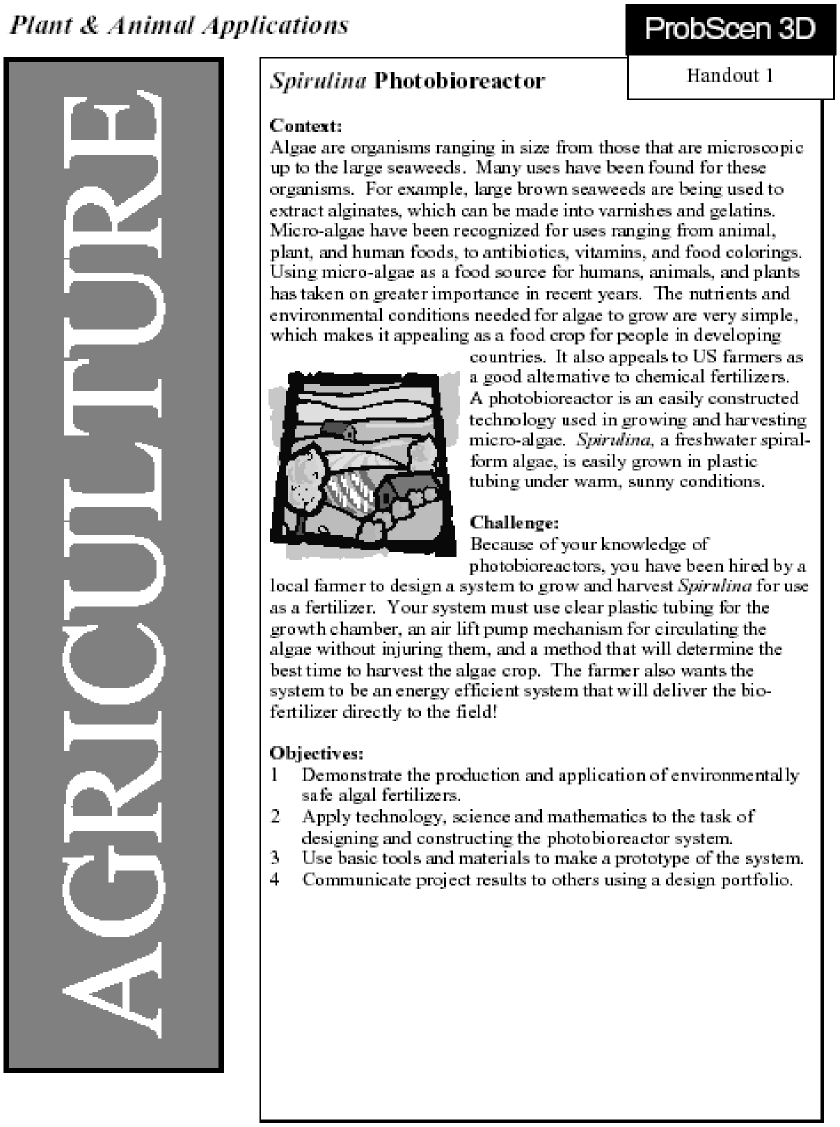
Appendix A

Photobioreactor Activity Context and Challenge (Wells, et al., 2000b)



Plant & Animal Applications

ProbScen 3D

Handout 1

AGRICULTURE

***Spirulina* Photobioreactor**

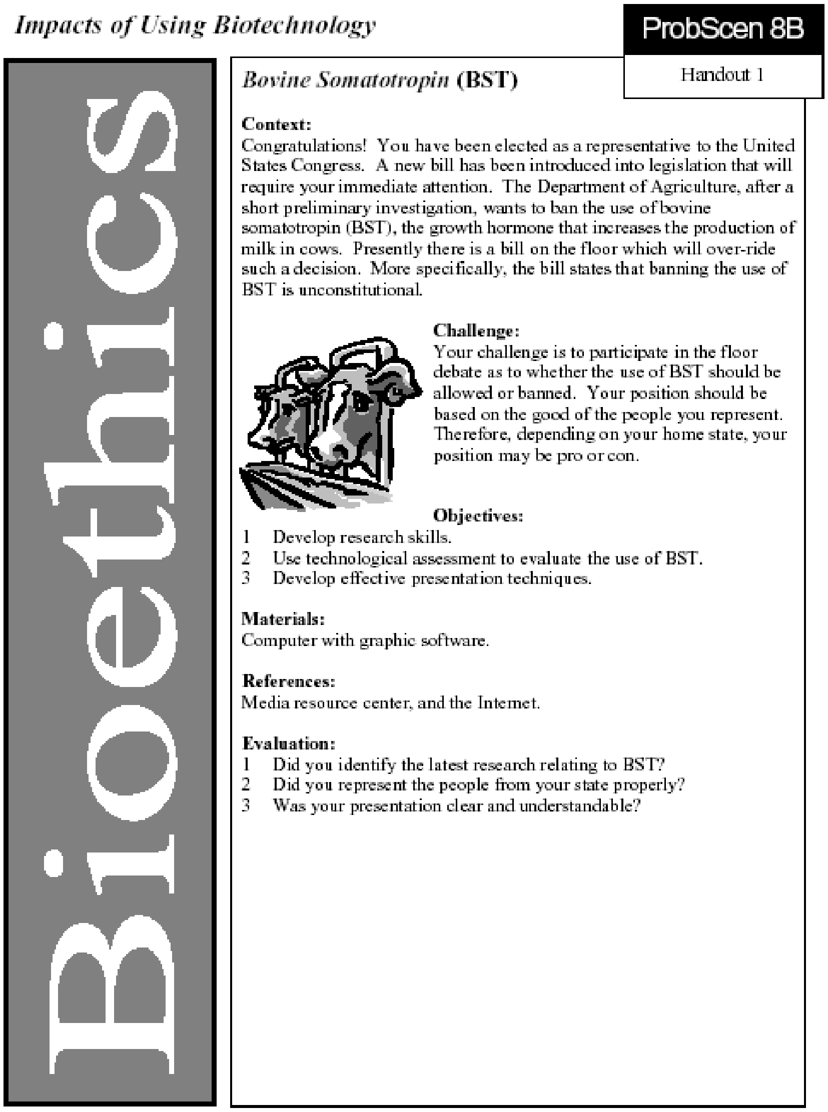
Context:
Algae are organisms ranging in size from those that are microscopic up to the large seaweeds. Many uses have been found for these organisms. For example, large brown seaweeds are being used to extract alginates, which can be made into varnishes and gelatins. Micro-algae have been recognized for uses ranging from animal, plant, and human foods, to antibiotics, vitamins, and food colorings. Using micro-algae as a food source for humans, animals, and plants has taken on greater importance in recent years. The nutrients and environmental conditions needed for algae to grow are very simple, which makes it appealing as a food crop for people in developing countries. It also appeals to US farmers as a good alternative to chemical fertilizers. A photobioreactor is an easily constructed technology used in growing and harvesting micro-algae. *Spirulina*, a freshwater spiral-form algae, is easily grown in plastic tubing under warm, sunny conditions.

Challenge:
Because of your knowledge of photobioreactors, you have been hired by a local farmer to design a system to grow and harvest *Spirulina* for use as a fertilizer. Your system must use clear plastic tubing for the growth chamber, an air lift pump mechanism for circulating the algae without injuring them, and a method that will determine the best time to harvest the algae crop. The farmer also wants the system to be an energy efficient system that will deliver the bio-fertilizer directly to the field!

Objectives:
1 Demonstrate the production and application of environmentally safe algal fertilizers.
2 Apply technology, science and mathematics to the task of designing and constructing the photobioreactor system.
3 Use basic tools and materials to make a prototype of the system.
4 Communicate project results to others using a design portfolio.

Appendix B

Bovine Somatotropin Activity Context, Challenge and Evaluation Questions
(Wells, et al., 2000b)



Impacts of Using Biotechnology

ProbScen 8B

Handout 1

Bioethics

***Bovine Somatotropin* (BST)**

Context:
Congratulations! You have been elected as a representative to the United States Congress. A new bill has been introduced into legislation that will require your immediate attention. The Department of Agriculture, after a short preliminary investigation, wants to ban the use of bovine somatotropin (BST), the growth hormone that increases the production of milk in cows. Presently there is a bill on the floor which will over-ride such a decision. More specifically, the bill states that banning the use of BST is unconstitutional.

Challenge:
Your challenge is to participate in the floor debate as to whether the use of BST should be allowed or banned. Your position should be based on the good of the people you represent. Therefore, depending on your home state, your position may be pro or con.

Objectives:
1 Develop research skills.
2 Use technological assessment to evaluate the use of BST.
3 Develop effective presentation techniques.

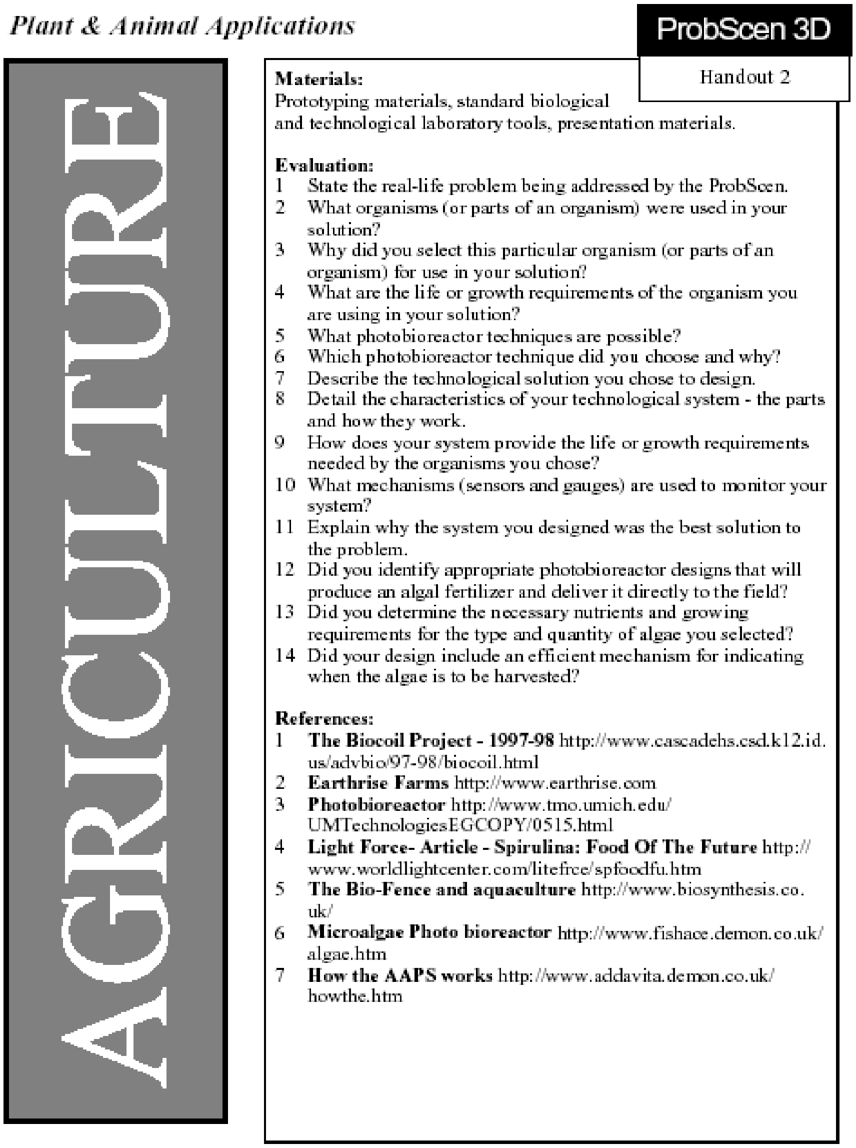
Materials:
Computer with graphic software.

References:
Media resource center, and the Internet.

Evaluation:
1 Did you identify the latest research relating to BST?
2 Did you represent the people from your state properly?
3 Was your presentation clear and understandable?

Appendix C

Photobioreactor Activity Evaluation Questions (Wells, et al., 2000b)



Plant & Animal Applications

ProbScen 3D

Handout 2

AGRICULTURE

Materials:
Prototyping materials, standard biological and technological laboratory tools, presentation materials.

Evaluation:
1 State the real-life problem being addressed by the ProbScen.
2 What organisms (or parts of an organism) were used in your solution?
3 Why did you select this particular organism (or parts of an organism) for use in your solution?
4 What are the life or growth requirements of the organism you are using in your solution?
5 What photobioreactor techniques are possible?
6 Which photobioreactor technique did you choose and why?
7 Describe the technological solution you chose to design.
8 Detail the characteristics of your technological system - the parts and how they work.
9 How does your system provide the life or growth requirements needed by the organisms you chose?
10 What mechanisms (sensors and gauges) are used to monitor your system?
11 Explain why the system you designed was the best solution to the problem.
12 Did you identify appropriate photobioreactor designs that will produce an algal fertilizer and deliver it directly to the field?
13 Did you determine the necessary nutrients and growing requirements for the type and quantity of algae you selected?
14 Did your design include an efficient mechanism for indicating when the algae is to be harvested?

References:
1 **The Biocoil Project - 1997-98** http://www.cascadehs.csd.k12.id.us/advbio/97-98/biocoil.html
2 **Earthrise Farms** http://www.earthrise.com
3 **Photobioreactor** http://www.tmo.umich.edu/UMTechnologiesEGCOPY/0515.html
4 **Light Force- Article - Spirulina: Food Of The Future** http://www.worldlightcenter.com/litefrce/spfoodfu.htm
5 **The Bio-Fence and aquaculture** http://www.biosynthesis.co.uk/
6 **Microalgae Photo bioreactor** http://www.fishace.demon.co.uk/algae.htm
7 **How the AAPS works** http://www.addavita.demon.co.uk/howthe.htm

Miscellany

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