Contents

From the Editor

Articles

Editorial

Miscellany

From the Editor

Building upon Our Melting Pot of Technological Diversity: A Lesson from Butte

I grew up in Montana and became very interested in the history of the city of Butte after working there as an engineering aide at an electrical power company while I was going to college. At one time, Butte was considered to be the mining capitol of the world and is still referred to as "The Richest Hill on Earth." Once word got out about the abundance of resources in the area in the late 1800s, immigrants came in droves to find a new beginning and a better life there. Initially, the Irish, Italians, and the "Cousin Jacks" from Cornwall, England settled in the area, followed by people representing nearly every nation in the world. Butte was considered by some to be one of the most culturally diverse cities in America in those early years.

As was true in virtually every older city, the new settlers carved out areas of the town so that others of their same nationality and language would settle there with them. There was deep distrust across ethnic sectors. Even though some nationalities shared a common religion, the churches to which they belonged were marked out ethnically. For example, there were Irish Roman Catholic churches and there were Italian Roman Catholic churches. Mines were divided by ethnic boundaries as well: the Never Sweat mine, for example, was the exclusive domain of the Irish for several decades.

Such situations continue today, over a century later, as immigrants settle in America, seeking out the larger cities for their greater potential for employment. Schools struggle to figure how to deal with students for whom English is a second language – if they can speak English at all. The same distrust and misunderstandings that existed in Butte in the 1800s still occur today as new ingredients are added to the melting pot of America.

It occurred to me that there are some parallels in the foregoing to technology education. A number of different, diverse "communities" have existed within the field over the years and many continue in various degrees today. There are some in our profession who still believe that teaching the use of tools is most important while others believe that conceptual knowledge should be the goal. Some believe in vocational education purposes while others are adamant about general education. Some value engineering design while others value aesthetic design; still others do not value design at all. Some have embraced our Standards while others have rejected them. Among those who embrace the Standards are those who do not accept biotechnology, medicine, and agriculture; a subgroup has even rejected all of the Standards by virtue of their disdain for the inclusion of these three areas. Some embrace distance education while others feel it is eroding the quality of our profession. Some feel that "board and t-square" drawing should continue to be taught while others feel that only computer-based visual expression should be included. Some are passionate about emphasizing engineering concepts, even suggesting we rename our profession as engineering education, while others are diametrically opposed to engineering.

There are a variety of sub-communities within virtually all subject areas in the schools. In agriculture education there are those who still believe in the value of agricultural mechanics and welding as the focus while others believe that the emphasis should be agricultural sciences and biotechnology. Right now in mathematics there are some who are promoting the elimination of the teaching of fractions while others are in disbelief that this notion would even be suggested. Social science educators range from one extreme to the other regarding the need to teach historical facts. Perhaps, though, nothing compares to issues regarding evolution, creationism, and intelligent design in the science community. In addition, the science community also has to reconcile the differences that occur from the fact that there are three different sources of curricular standards: the American Association for the Advancement of Science (AAAS), the National Research Council's National Committee on Science Education Standards and Assessment (NCSESA), and the National Science Teachers Association (NSTA). Within the triangle of these standards is the issue of eliminating the "layer cake approach" of separate courses in earth science, biological science, and physical science and, instead, including all three areas in all the courses the students take.

Divergent points of view and philosophies are healthy for any profession and are often the seeds from which positive change grows. As I reflect on this over the past forty years, it does seem that we have had a lot of seeds planted, perhaps more than any other subject in education. Some sprouted up and looked sturdy and healthy at first, but later withered and died when they were no longer nurtured. Others came up as weeds. Some, however, took deep roots and became the foundation of what was to come.

In addition to all the proposals for change that have been put before the profession, in recent years there have been many "immigrants" into the profession. They differ significantly from those who started a career as a technology teacher fresh out of college at the age of twenty or so. Among them are those who were prepared as teachers in the field, but decided to pursue a career outside of teaching for a while and are now entering teaching for the first time. A lot has changed since these folks graduated. There are those who are career switchers, obtaining licensure as a technology teacher with a degree in another field, after spending time in business, industry, or the military. There are those who are licensed to teach in other fields and decided to switch to technology education, either due to personal interest or by necessity.

Increasingly, those with degrees in engineering are entering the profession. Adding to the complexity is the variability in the programs in which these teachers were prepared and *when* they were prepared. Some come from programs that have a vocational orientation and a concomitant emphasis on technical skill. Some come from programs that are based on the Standards while others come from programs that closely resemble the industrial arts programs of the 1960s. Some learn the technical content through courses that serve prospective teachers, along with those bound for careers in industry. For some, all of the professors in their major have degrees in technology education while for others this is the exception. For some, their hands-on lab experience was working with tools and materials to solve technological problems, while for others their problem-solving tool was principally a computer. Yet others have had virtually no technological problem solving experience at all. For some, the majority of their course work was delivered virtually over the Internet, and nearly every recent graduate has completed at least one course online. Some have a significant number of courses in mathematics and science while others have a minimal exposure to these subjects. Likewise, some embrace mathematics and science while others hold these two disciplines in contempt because of negative experiences. Arguably, we have the most diverse array of teachers in the schools. Arguably, as well, we have had more initiatives for significant change in our curricula and methods over the past several decades than any other teaching area.

The proposals for change in our profession over the years have not simply been a reordering or recombination of subjects, or simple tweaks in how we approach laboratory instruction. Rather, they are major changes that have required a complete overhaul of the value system of our profession and the individual members within it. Moreover, this overturn in values has not been expected just once, but several times. Though this treatise reflects what has happened in the US, I am confident that our international colleagues have comparable stories to tell.

Though the Standards are logical, needed, and rational, they do not necessarily address the problem with changing the core values of the teachers to whom they are directed. People do not generally behave in a way that is inconsistent with personal values and let us not kid ourselves – our teachers are the bottom line in our efforts to change.

The challenge to bring a consistent set of values to the diverse members of our profession is indeed formidable, yet essential, if we are to realize our ideals and provide a viable, enriching, defensible, and reasonably consistent experience to the students we serve. Values are based on beliefs and beliefs are tied to emotions. Emotions are the windows to our inner-selves, yet they can be our most irrational attribute. Rampant, uncontrolled emotions can lead to poor decision making. The history of the world is filled with the frightening results of emotions that have gone out of control.

Indeed, the diversity of our profession is comparable to the many cultures in the early mining city of Butte, Montana, with all the emotional underpinnings that accompany them. Mining in Butte is almost gone and it is now the largest environmental disaster Superfund site in the US. Despite the challenges Butte faced, they pulled together and I do not know of a city that has a higher spirit of community. Today, the Irish in Butte enjoy eating a Cornish pastie just as much as Cousin Jacks enjoy corned beef and cabbage. What's more, they can enjoy the food and each others' company while sitting at the same table. They did not get there, though, by putting fences around their ethnic neighborhoods nor did they get there by "picking up their toys and going elsewhere." They communicated and built trust, and they grew to respect and appreciate their divergent values, building their community upon them. They were able to meld their personal values together with the values of the community as a whole. They faced the challenges together and met them – together.

JEL

Articles

Curricular Value and Instructional Needs for Infusing Engineering Design into K-12 Technology Education

David K. Gattie and Robert C. Wicklein

Introduction

An overarching objective of Technology Education in the U.S. is to improve technological literacy among K-12 students (DeVore, 1964; Savage and Sterry, 1990; International Technology Education Association, 1996, 2000, 2003). This is addressed in part through a focus on end-product technology and the use and importance of various technologies in society (Savage and Sterry, 1990). While such a focus is certainly necessary, it may not be sufficient if the objective is to infuse engineering into the technology education field. Current efforts at the University of Georgia propose adjusting the focus of Technology Education to a defined emphasis on engineering design and the general process by which technology is developed. Such an emphasis has the potential for providing a framework to: 1) increase interest and improve competence in mathematics and science among K-12 students by providing an arena for synthesizing mathematics and science principles, and 2) improve technological literacy by exposing students to a more comprehensive methodology that generates the technology. This will inherently raise mathematics and science requirements for technology teachers and technology teacher educators. Moreover, general textbook and instructional material needs for teaching technology education with an engineering design focus will undergo change.

Among the National Science Board's key recommendations in its report on the science and engineering workforce is an emphasis on in-service training and support for pre-college teachers of mathematics, science, and technology as an integral part of the scientific and engineering professions (National Science Board, 2003). This recommendation emphasizes a critical need to develop experiences for K-12 students in engineering. Furthermore, it accentuates the

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necessity for long-term opportunities to prepare in-service teachers in the synthesis of mathematics, science and engineering. This paper proposes the field of technology education as fertile ground for developing an institutional, systemic approach to the needed synthesis of science, technology, engineering, and mathematics (STEM) in K-12 education.

Technology education as a specialized area within the field of K-12 education has undergone a metamorphosis over the past two decades with respect to guiding principles, objectives, purpose, and goals. Early foundations were based on industrial arts with the objective to educate high school students in aspects of an increasingly more industrialized society. The name technology education was officially adopted by the primary professional association, the International Technology Education Association, on February 20, 1985 to reflect the field's transition toward an educational focus on the technological underpinnings of society (Phillips, 1985). To a certain extent, this transition reflected an effort within the general K-12 educational scheme to prepare non-college bound high school graduates to directly enter the workforce with a suite of technological skills. Each transition in the growth and development of the field was accompanied by an appropriate shift in the educational schema for teacher educators and in-service teachers.

Current issues of concern for the overall academic K-12 education subjects have developed due to low nationwide performance in mathematics and science subjects, and a general absence of K-12 programs that motivate and prepare students to consider engineering as a career option (Dearing and Daugherty, 2004). Recently, the field of technology education has attempted to address these concerns by incorporating engineering concepts into its educational schema, thereby providing a formal structure for synthesis of science, mathematics, and technology. The Standards for Technological Literacy (STL) defines what students should know and be able to do in order to be technologically literate and provides standards that prescribe what the outcomes of the study of technology in grades K-12 should be (International Technology Education Association, 2000). This is a defined set of twenty technological literacy standards grouped into five general categories: 1) the nature of technology; 2) technology and society; 3) design; 4) abilities for a technological world; and 5) the designed world. For each standard, benchmarks of academic achievement have been defined for educational grade levels K-2, 3-5, 6-8, and 9-12. Noteworthy, is the inclusion of "design" as one of the general groups. Grades 9-12 are of particular interest as this is often the point in the K-12 education experience when students begin making long-range plans for attending college or vocational school or for joining the workforce. While this is not necessarily the optimal point for introducing engineering concepts, there is a sufficient structure of technology education to assess teacher perspectives regarding engineering design. It may very well be that in the long term, in order to infuse engineering into K-12, a systemic approach whereby grade levels K-2, 3-5, 6-8, and 9-12 are served with appropriate engineering pedagogy would have the greatest impact. However, this effort focused on 9-12 in order to develop initial insight of well-developed areas within the overall technology education landscape.

While the infusion of design into technology education is being built into several programs across the U.S., the interpretation and meaning of design is not necessarily standardized or formally defined within the technology education field. A particular point of departure among the various programs, however, emanates from varied interpretations of design and the approaches by which design is infused into technology education. While various definitions of design are not the fundamental issue, efforts to infuse engineering design into technology education programs would perhaps benefit from at least a common starting point so that academic and research efforts are normalized. This may also provide clarity for in-service teachers as they change curricula to reflect national needs and trends.

Recently, Wicklein (2006) proposed that the field of technology education adopt an interpretation of design based on the engineering definition alone, and suggested that the most appropriate approach for infusing engineering into technology education is by establishing engineering design as the focus. The basis for the assertion is fivefold: 1) engineering design is better understood and valued than technology education; 2) engineering design elevates the field of technology education to a higher academic and technological level; 3) engineering design provides a defined framework to design and organize curricula; 4) engineering design provides an ideal platform for integrating mathematics, science and technology; and 5) engineering provides a focused career pathway for students. Additional efforts in the infusion of engineering design into technology education have been established in a growing number of university instructional programs (e.g. Utah State University; The College of New Jersey; The University of Georgia, Illinois State University, Brigham Young University, and Virginia Polytechnic Institute and State University). In particular, the National Science Foundation's funding and establishment of the National Center for Engineering and Technology Education (NCETE), a collaboration of nine institutional partners focused on infusing engineering design into technology education, reflects commitment at the highest levels. Moreover, fledgling efforts exist within K-12 education and teacher educator environments in the U.S. to prepare teachers and students for teaching and learning technology from an engineering design perspective, with various methodologies for doing so.

As such a redirection that infuses engineering design into technology education would represent fundamental change within the field, general challenges have been identified which will require an assessment of the current state of the field as well as an assessment of the impending needs that will accompany the change. These challenges reflect the authors' experiences and discussions with in-service teachers and technology teacher educators who are working to infuse engineering design into technology education. The general challenges for technology education associated with this fundamental change are identified as: 1) current low-level mathematics requirements in technology education university preparation programs; 2) entrenched traditional views of K-12 technology education as non-college bound preparatory; 3) inconsistent interpretation of engineering *design* within the field ; 4) insufficient instructional resources; 5) inadequate or inappropriate laboratory configurations; 6) negatively biased school decision makers regarding technology education.

Research Goals

This paper presents one element of the University of Georgia's efforts to affect fundamental change based on a national survey of in-service K-12 technology education teachers who use the Standards for Technological Literacy as a guide. Results from the survey are presented and address three areas: 1) the current practices of technology teachers in relation to utilizing engineering design practices within the high school technology education classroom; 2) the value of an engineering design focus for technology education; and 3) the instructional needs of high school teachers of technology education related to engineering design. Results indicate that over 90% of in-service technology education teachers identify engineering design as the appropriate focus for their instructional program, and an equal number recognize that levels of mathematics and science skills, above current requirements, are needed. Moreover, two-thirds identify current technology education teaching materials as inadequate for re-focusing efforts on engineering design. These data provide baseline information reflecting current perspectives of in-service teachers, and give insight into their attitudes about the infusion of engineering design into technology education.

Methods

Survey-based research methodologies were deemed appropriate for collecting data to obtain standardized information from the most knowledgeable subjects integral to this topic. A population consisting of the 1063 in-service high school technology educators who were members of the International Technology Education Association (ITEA) was selected. ITEA is the largest professional educational association, principal voice, and information clearinghouse devoted to enhancing technology education through experiences in K-12 schools. From this population, a stratified, random sample of 583 of these high school teachers was selected, with the four regions of the ITEA serving as the strata. A survey instrument was sent to this sample. These individuals represent a cross-section of high school technology education teachers. However, because the population was delimited to ITEA members only, the results cannot be generalized to the majority of teachers who are not members. A total of 283 usable surveys were returned for analysis through the efforts of an initial and follow-up survey probe, and represented a 48.5% return rate: 104 (36.7%) from the East region, 67 (23.6%) from the East Central region, 76 (26.8%) from the West Central region, and 36 (12.7%) from the West region). Four subject areas were evaluated: 1) demographics; 2) current instructional practices; 3) value of engineering design for the technology education curriculum; and 4) instructional needs related to teaching engineering design. These areas reflect concepts developed from the authors' professional experience, discussions at workshops and conferences, and feedback from various focus groups. The areas are necessarily broad by design as this study represents an initial step toward developing a broad vision of the technology education landscape with respect to the needs associated with engineering design. The instrument was carefully written so that the meaning of engineering design was clearly defined, and all answers were based on a common foundation. The following statement was provided on each page of the survey instrument:

> 'Engineering Design' Defined:
> Engineering design, also referred to as technological design, demands critical thinking, the application of technical knowledge, creativity, and an appreciation of the effects of a design on society and the environment. The engineering design process centers around four (4) representations used to describe technological problems or solutions: (1) **Semantic** – verbal or textual explanation of the problem, (2) **Graphical** – technical drawing of an object, (3) **Analytical** – mathematical equations utilized in predicting solutions to technological problems, (4) **Physical** – constructing technological artifacts or physical models for testing and analyzing (International Technology Education Association, 2000; Ulman, 2003).

Results

Respondents were predominantly male (87.2%) teaching at the high school level (92.5%) with an average of 17.4 years of teaching experience and an average age of 47. Only one-fourth (25%) have B.S./B.A. level degrees in technology education, while 43.8% have undergraduate degrees in industrial arts. About two-thirds (65%) have masters degrees, of which over half (59.2%) are in areas other than technology education and industrial arts (see Table 1).

The vast majority (90%) indicated that topics on engineering or engineering design are currently being taught in their courses with 45.4% of instructional content devoted to the subject. While almost 80% are satisfied with their own instructional methodology, over half (53.2%) are not satisfied with current instructional materials. Most (87.4%) do not identify any constraints to including engineering design content in their curriculum, but only half (54.2%) are aware of local or state approved courses or curricula that focus on engineering or engineering design (see Table 2).

Respondents expressed confidence that an engineering design curriculum focus would add value to the field of technology education by: clarifying the focus of the field (93% agreement); providing a platform for integration with other school subjects (96.7% agreement); elevating the field to higher academic levels (92.7% agreement); improving instructional content (88.4% agreement); increasing student interest in mathematics and science (89.3% agreement); and providing additional learning opportunities for students (94.4% agreement) (see Table 3).

Table 1
Summary of results regarding demographics

Demographic Criteria	**Response**
Years experience (mean)	17.4
Level at which currently teaching	Middle School – 3.5% High School – 92.5% Other – 3.8%
Gender	Male – 87.2% Female – 12.0%
Average Age	47
College Degrees Obtained	B.S./B.A. 30.0% Masters – 65.0% Ed.S-Specialist – 2.4% Ed.D – 0.3% Ph.D – 2.1%
College Major	B.S./B.A. Level Industrial Arts – 43.8% Technology Education. – 25.0% Other- 31.2% Masters Level Industrial Arts – 16.8% Technology Education – 24.0% Other – 59.2%

Table 2
Summary of results regarding current instructional practices

Survey Item	**Response**
Do you currently teach topics/courses that are related to engineering or engineering design?	Yes – 90.0% No – 9.3%
What percentage of your teaching instruction is related/connected in any way to engineering or engineering design?	45.4% (mean)
If you are teaching engineering or engineering design how satisfied are you with your current instructional methodology?	Extremely Satisfied – 12.9% Satisfied – 66.0% Dissatisfied – 19.1% Extremely Dissatisfied – 2.0%
If you are teaching engineering or engineering design how satisfied are you with your engineering related textbooks or text materials?	Extremely Satisfied - 2.8% Satisfied – 44.0% Dissatisfied – 41.2% Extremely Dissatisfied – 12.0%
Are you under any administrative (local or state) constraints to limit/exclude engineering or engineering design instructional content in your technology education curriculum?	Yes – 12.6% No – 87.4%
Are you aware of any local or state approved course(s) or curriculum that has a focus on engineering or engineering design?	Yes – 54.2% No – 45.8%

Table 3
Summary of results regarding the value of engineering design for technology education. Emboldened values indicate highest level; italicized values indicate second highest level.

An engineering design curriculum would:	**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Help clarify the focus for technology education	2(0.7)	17(6.3)	**152(56.3)**	*99(36.7)*
Increase the overall academic value of technology education	0	14(5.1)	**131(48)**	*128(46.9)*
Provide a platform for integration with other school subjects	1(0.4)	8(2.9)	**139(50.5)**	*127(46.2)*
Elevate technology education to higher academic levels	1(0.4)	19(7)	*113(41.4)*	**140(51.3)**
Elevate technology education to higher technological levels	1(0.4)	15(5.5)	**129(47.6)**	*126(46.5)*
Provide a more focused career pathway for students	4(1.5)	31(11.7)	**145(54.9)**	*84(31.8)*
Improve the academic value of technology education in the minds of students	2(0.7)	34(12.6)	**130(48.1)**	*104(38.5)*
Improve the academic value of technology education in the minds of parents	1(0.4)	16(5.7)	**132(49.1)**	*120(44.6)*
Improve the academic value of technology education in the minds of school administrators	5(1.8)	18(6.7)	*115(42.9)*	**130(48.5)**
Improve the instructional content for technology education	2(0.7)	29(10.9)	**142(53.2)**	*94(35.2)*
Improve coverage of technological literacy content within technology education	0	30(11.3)	**141(53.2)**	*94(35.5)*
Increase student interest and appreciation for mathematics and science	3(1.1)	25(9.5)	**129(49.2)**	*105(40.1)*

Table 3 (continued)
Summary of results regarding the value of engineering design for technology education. Emboldened values indicate highest level; italicized values indicate second highest level.

An engineering design curriculum would:	**Strongly Disagree**	**Disagree**	**Agree**	**Strongly Agree**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Provide additional learning opportunities that would open career options for students	0	15(5.5)	**150(55.1)**	*107(39.3)*
Elevate the technology teacher as a more valued member of faculty	2(0.8)	49(18.9)	*92(35.5)*	**116(44.8)**

Table 4
Summary of results pertaining to instructional needs to support the teaching of engineering design. Emboldened values indicate highest level; italicized values indicate second highest level.

My instructional needs to teach engineering design include:	**Strongly Agree n(%)**	**Disagree n(%)**	**Agree n(%)**	**Strongly Agree n(%)**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Identifying appropriate instructional content	4(1.5)	20(7.3)	**167(61.2)**	*82(30)*
Determining the appropriate level of instruction	5(1.9)	23(8.6)	**162(60.7)**	*77(28.8)*
Integrating the appropriate levels of mathematics and science into the instructional content	2(0.7)	15(5.5)	**156(56.7)**	*102(37.1)*
Gaining the appropriate levels of mathematics and science knowledge to teach engineering design	5(1.8)	35(12.8)	**136(49.8)**	*97(35.5)*
Locating appropriate textbooks and associated text materials	4(1.5)	24(8.8)	**142(52.2)**	*102(37.5)*

Table 4 (continued)
Summary of results pertaining to instructional needs to support the teaching of engineering design. Emboldened values indicate highest level; italicized values indicate second highest level.

My instructional needs to teach engineering design include:	**Strongly Agree n(%)**	**Disagree n(%)**	**Agree n(%)**	**Strongly Agree n(%)**
	n(%)	***n(%)***	***n(%)***	***n(%)***
Having the appropriate types of tools and test equipment to teach engineering design	1(0.4)	20(7.2)	*110(39.9)*	**145(52.5)**
Having the appropriate type of laboratory layout and space to teach engineering design	2(0.7)	21(7.7)	*111(41)*	**137(50.6)**
Developing additional analytical (mathematics) skills to be able to predict engineering results	3(1.1)	33(12.2)	**151(55.7)**	*84(31)*
Improving fundamental knowledge of engineering sciences (statics, fluid mechanics, dynamics)	5(1.8)	20(7.2)	**149(54)**	*102(37)*
Having access to practicing engineers to give consultation and oversight	2(0.7)	27(10)	**147(54.2)**	*95(35.1)*
Establishing a support system with mathematics and science faculty	2(0.7)	34(12.5)	**148(54.4)**	*88(32.4)*
Garnering the support of school administrators and counselors	5(1.8)	22(8)	121(43.8)	**128(46.4)**
Seeking the promotion of the engineering/engineering design curriculum by school administrators	6(2.2)	18(6.6)	**135(49.6)**	*113(41.5)*

Results from the assessment of instructional needs indicate that the in-service technology educators in the sample recognize the need to improve their own level of knowledge pertaining to engineering design subject matter. With respect to integration of appropriate levels of mathematics and science into their instructional content, 93.8% recognize this as a need, and 85.3% acknowledge that gaining the appropriate levels of mathematics and science knowledge to teach engineering design is necessary. Moreover, 86.7% agree that developing additional analytical (mathematics) skills and 91% agree that improving fundamental knowledge of engineering sciences are needed to teach engineering design appropriately at the high school level (see Table 4).

Discussion

A comparison of the technology education design process, as defined by the Standards for Technological Literacy, with a general description of the steps involved in the engineering design process, reflects a fundamental distinction with regard to mathematics and analysis (Table 5) (International Technology Education Association, 2000; Eide, Jenison, Mashaw, and Northup, 2001). It is noted that the engineering design process is iterative and not strictly linear, although the categories in the figure reflect the general steps involved. The technology education design process is directed toward the construction of a prototype model that can be tested for failure or success, but lacks the mathematical rigor that would enable the process to be repeated. Moreover, the absence of analysis precludes the development of predictive results. This fundamental difference is the basis for change within the current technology education framework suggested in this paper, and is reflected by the survey results.

Table 5
A comparison of design processes

Engineering Design Process (Eide, et.al., 2001)	**Technology Education Design Process** (ITEA, 2000)
1. Identify the Need	1. Define problem
2. Define Problem	2. Brainstorming
3. Search for Solutions	3. Research & Generate Ideas
4. Identify Constraints	4. Identify Criteria
5. Specify Evaluation Criteria	5. Specify Constraints Explore Possibilities
6. Generate Alternative Solutions	6. Select an Approach
7. Analysis	7. Develop a Design Proposal
8. Mathematical Predictions	8. Build a Model or Prototype
9. Optimization	9. Test & Evaluate the Design
10. Decision	10. Refining the Design
11. Design Specification	11. Communicating Results
12. Communicate Design Specifications	

While 90% of the technology educators surveyed teach topics or courses in or related to engineering or engineering design, the mathematics requirements for undergraduate degrees in the technology education field are typically not beyond college algebra or trigonometry. This apparent paradox may help explain why 85% of the respondents also recognize that improvement in analytical skills, science knowledge, and engineering science is necessary for them to teach engineering design adequately. This is also a reasonable basis upon which to question the levels to which formal engineering design is being integrated into the K-12 experience in the U.S., even among those who make the effort to do so. At the undergraduate level, introductory engineering design is taught at the freshman level with a minimal mathematics requisite or co-requisite of differential calculus. Concepts of rates, limits, and maximum/minimum are already being instilled and can be drawn upon as the college engineering curriculum advances through integral and vector calculus, differential equations, and linear algebra. At least one major challenge confronting efforts to infuse engineering design in K-12 education is the development of a pedagogical framework that builds upon a mathematical foundation that begins with elementary algebra and culminates with calculus. This framework will also entail the need for novel instructional materials that creatively develop the concepts of engineering design in K-12 without sacrificing the critical steps of engineering analysis. It is plausible that this indicates a level of dissatisfaction with current technology education instructional materials and textbooks. At least one reason for this dissatisfaction could be that a focus on technological literacy alone is inadequate for teaching analytical methodologies of engineering design.

While the STL's (Standards for Technological Literacy) include references to design, "engineering design" is mentioned in only one of the standards, while mathematics and science are not mentioned at all. This may lead to a fuzzy, non-focused basis for infusing engineering design into technological literacy. STL standard #3 states, "Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study." The benchmark for this standard is given as, "Technological progress promotes the advancement of science and mathematics." This implies that science and mathematics are closely related to technology. However, this relationship is realized only through the engineering design process that produces the technology. The need for and usefulness of science and mathematics are not comprehended through technological literacy alone. However, the engineering design process that develops the technology offers a framework within which science, mathematics, and technology can be pedagogically contextualized and analysis can be integrated directly. Survey respondents recognize this as evidenced by their support for an engineering design focus as a platform to integrate technology education with other school subjects such as mathematics and science. Within technology education, the current focus on the technology produced by the engineering design process engenders a certain level of technological literacy, but does not necessarily synthesize mathematics and science in that focus.

Standard #8 states, “Students will develop an understanding of the attributes of design,” followed by standard #9 which states, “Students will develop an understanding of engineering design.” In both cases, mathematical analysis is not mentioned as a benchmark for any of the K-12 grades. Since these are standards to which in-service technology educators adhere, these two standards might foster a variety of interpretations of design. As mathematics and science are not listed as benchmarks for either standard # 8 or #9, it is difficult to understand the role of engineering design within technology education. In light of this, respondents appear to agree that engineering design is the appropriate approach for clarifying the focus of technology education.

Conclusion

Within science education, the scientific method is as necessary as the scientific principles. We propose a parallel line of reasoning for the engineering and technology education wherein the design methodology that produced the technology is as important as the artifact of technology itself. Respondents to this survey agree that an engineering design focus for technology education would be a valuable contribution, although they realize their own limitations due to academic training and educational resources. However, the results of this study are not proposed as a sufficient edict on the current landscape of technology education; rather, it serves as a step toward a more lucid view of the landscape and into how well-prepared in-service teachers see themselves for teaching a design methodology that includes mathematical analysis. Infusion of engineering design into technology education will require a steady, focused effort. This effort, however, is not simply to draw students into engineering careers. Rather, it is viewed as a contribution to the K-12 education system in general as it provides the opportunity for students to realize the usefulness of and need for mathematics and science as they apply to their lives through technology, understanding it within the context of the engineering design methodology.

The benefits of an engineering design focused curriculum for technology education have potentially broad ramifications. If done deliberately and with academic rigor, technology education can be identified in an entirely different light. Students and parents will see a curriculum that is organized and systematic, leading to valued career options. School administrators and counselors will have a curriculum that provides multiple options for students, both college-bound and non-college bound. Engineering educators will receive a better-prepared student who understands engineering design processes at the onset of their college experience. Business and industry will have a greater number of U.S. citizens entering the engineering workforce. This is a viable future for technology education and a needed contribution to the engineering profession. The question remains, “Are K-12 and the engineering profession prepared and willing to accept this formidable but worthwhile challenge” (Dearing and Daugherty, 2004, p.11)?

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Using Talking and Drawing to Design: Elementary Children Collaborating With University Industrial Design Students

Brenda Gustafson, Dougal MacDonald, and Shannon Gentilini

Study Purpose

In this study, Grade 3 (ages 8-9) children's talking and drawing were explored as they worked with university industrial design students to design and redesign drawings of a piece of furniture and produce a poster of their work. The researchers proposed that ideas about talking and drawing derived from interactions between children and the design students could be useful for discerning possibilities for children's classroom talking and drawing. The purpose of the study, therefore, was to provide insight into how talking and drawing could be used as tools for thinking about designs and how those insights could provide direction for teaching design technology in elementary classrooms.

Theoretical Framework

In recent years, much research has focused on how language contributes to learning (Hodson, 1998; Orsolini & Pontecorvo, 1992; Parker, 1992; Wells, 1995). Researchers describe language as being fundamental to children's knowledge construction and a tool for thinking (Hodson, 1998; Orsolini & Pontecorvo, 1992; Parker, 1992).

In design technology, talk is a verbal tool that children can use to develop ideas and communicate design thought. Discourse essentially involves the manifestation or expression of design ideas that allows children to take design ideas forward. Researchers have conducted classroom studies based on the belief that design technology is a social process in which learning is enhanced through talk that supports the construction of meaning about artifacts and devices (Anning, 1997b; Bennett & Dunne, 1991; Hennessy & Murphy, 1999; Rath & Brown, 1996; Roden, 1999; Roth, 1995, 1997; Shepardson, 1996).

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These studies provide preliminary evidence of the nature of children's talk during design technology activities. Researchers note that task-setting and purpose influence modes of talk, that a variety of modes of talk may be evident in any one particular activity, and that talk seems rarely to be devoted to the conceptual underpinnings of the lesson. During technology tasks, children can display flexibility in their thinking as they negotiate the task and work with others to achieve the objective. Although these findings provide useful groundwork, much has yet to be done as far as shaping these and other observations into a framework that lends itself to critical analysis that assists in identifying what children's technology talk could be.

A smaller number of studies have focused on how design professionals use talk to further the design process (Cross & Cross, 1998; Darke, 1979). Some researchers have speculated that professional discourse practices can provide some indication of the kinds of design talk that could be promoted during children's classroom design experiences (Gustafson & MacDonald, 2004; Hill & Anning, 2001a, b). Studies show that professionals' verbal decision-making includes using talk to frame the problem, gain an overview of the problem space, discuss constraints, make decisions, and discuss design trade-offs. Although researchers caution that professional discourse practices do not map directly onto the classroom, at the least these studies provide an overview of possibilities for children's design talk.

Other strategies that can be used to generate, explore, and modify design technology ideas include drawings, observing and recording, and building prototypes (Kimbell, Stables, & Green, 1996). Within this array, drawing is the visual tool that professional designers view as being the critical medium of design (Cross, 1989; Robbins, 1994). Designers view drawing not just as a way of recording images but as a concrete mode of thought, a mediating instrument between mind and hand, between abstract thought and reality. Drawings are used to both represent and to generate ideas. For the design of most complex products, this means that thousands of drawings may be necessary. Because it has been suggested that designers not only communicate visually but also think visually, we refer to the processes represented by the drawings as visual decision-making.

Recent research on classroom drawing in design technology has focused on four main questions: How is drawing used as a means of creating and developing ideas? What is the link between drawing and making? What are the respective roles of 2-dimensional and 3-dimensional modeling? And what are the effects of the explicit teaching of drawing? Researchers report that classroom design technology drawing overemphasizes the role of drawing in representing and communicating ideas and under-emphasizes its role in generating ideas (Anning, 1997a; Garner, 1992, 1994; Hope, 2000; MacDonald & Gustafson, 2004; MacDonald, Gustafson, & Gentilini, 2007; Smith, 2001). Disparate findings have been reported on whether or not children use their drawings to assist with building (Fleer, 2000; Rogers, 1998). Children have been found to prefer 3-dimensional modeling to 2-dimensional drawing and appear reluctant to use sketch drawings (Smith, 2001; Welch, 1998). Researchers have recommended that a potential strategy to enhance children's use of design drawing is to teach children drawing skills in an effort to make them more aware of the ways drawing can contribute to their designs (Fleer, 2000; Smith, 2001; Smith, Brochocka, & Baynes, 2001). These studies provide insight into the challenges of children's design technology drawing and show some promising direction for what children's design technology drawing could be.

In the study reported on in this paper, we propose that ideas about talking and drawing derived from interactions between children and university industrial design students can be useful for discerning possibilities for children's classroom talking and drawing. Studying professional practice is a longstanding tradition in education that in science education has led to the development of lists of science processes (AAAS, 1967), and in language arts education has led to the generation of the writing process (Walshe, 1981). In design technology, Davies (1996) argues that professional designers and children have much in common (e.g., thought processes and approaches to their work) that justifies using professional practice as a way to inform work with children. Medway (1994), however, warns that technological education is not technological practice as each works within a distinctively different matrix. In this study, we concur with Medway (1994) who concludes that studies of professional practice can provide indicators of curricular possibilities and add that studies of interactions between children and novice practitioners hold the possibility of assisting teachers to understand how to enrich children's design technology talking and drawing.

Basing the study on potential insights that can be observed through having children collaborate with a more knowledgeable person also draws upon ideas about scaffolding found in the social constructivist model of learning (Vygotsky, 1968). Scaffolding is the support provided to children by the knowledgeable other and can include recruiting the child's interest, highlighting critical aspects of the task, limiting task frustration, and demonstrating solution paths (Wood, Bruner, & Ross. 1976). A critical aspect of scaffolding is what Vygotsky terms the zone of proximal development (ZPD). The ZPD is described as the distance between the child's actual development and the higher level of potential development that could be achieved through the guidance of a more knowledgeable other (Wertsch, 1985). In design technology, some studies have focused on what might be involved in scaffolding children's design learning (Kolodner, et al., 2003; Puntambekar & Kolodner, 2005). Studies have helped to identify tools and agents of support and emphasize the importance of creating contexts in which learning conversations can occur.

Question: How can studying children as they work with university industrial designers provide direction for children's classroom talking and drawing?

Methodology

One elementary school located in an upper class, urban neighborhood was selected for the study. Researchers visited one Grade 3 (16 boys, 10 girls) Academic Challenge (e.g., gifted and talented) classroom during an 8-week unit on *Testing Materials and Designs* and *Building with a Variety of Materials*. Within the 8-week unit, the children studied drawing (2-dimensional and 3-dimensional), the design process, the importance of planning, furniture and structural design, and how to build with various materials.

This paper focuses on five weeks of the unit during which the children worked to design a piece of furniture that had more than one function (e.g., a lamp that illuminated a room and also contained an alarm that would warn of an intruder). The children's work began in their school classroom where they were introduced to the concept of design, taught drawing skills relevant to design, and taught the meanings of the terms furniture, need, and function. Each child then made three initial design drawings of their piece of furniture.

During the next few weeks, the children participated in three visits to a local university to work with industrial design students, collaborate on their furniture designs, and produce posters of their final design ideas. During the first visit, each child was paired with a university industrial design student who was referred to as a "Big Buddy." The children's initial design drawings were scanned into their Big Buddy's computers and the university industrial design students then provided the children with short explanations of the Rhino(ceros) graphics program being used. Over the next two visits, children worked with their Big Buddies to refine, improve, and complete the design. During the final visit, children shared their final designs with the class and the Big Buddies printed the design ideas onto posters. These posters were later exhibited at a venue during a local annual art show.

During the study, audiotapes were made of whole-class discussions that occurred prior to and after the university visits. Anecdotal records were kept of informal conversations with the teacher that occurred prior to and after each lesson. Lesson transcripts were provided to the teacher, and she was invited to amend or clarify the meaning of any verbal comments. Field notes and photographic evidence were compiled to gain insight into the children's interactions with each other in the classroom and with their assigned Big Buddies. Children's drawings and writings were photocopied and used to help interpret verbal comments. The children also completed a written pre- and post-study survey about their perceptions of design.

During the three university visits, audiotapes were made of four dyads, each consisting of a child (2 girls, 2 boys) working with an industrial design student. Transcripts were prepared from these audio-taped sessions. After each of the visits, the university industrial design students completed a post-visit questionnaire. Questions included asking about the children's tasks, decision-making, and design challenges and the nature of the university students' assistance and guidance.

Data Analysis

Audiotape transcript analysis of the four dyads (Ch1/USt1; Ch2/USt2; Ch3/USt3; Ch4/USt4) began with categorizing how the four children and their Big Buddies used talking and drawing to negotiate the nature and context of the task. Through multiple readings of the data, profiles were developed of the ways in which talking and drawing were used to achieve design solutions (Huberman & Miles, 1994). Industrial design student questionnaires derived from the entire class were used to expand the description of interactions between children (coded as Ch #) and university industrial designers (coded as USt #), and records of drawings and poster presentations were used to help clarify ongoing and final thoughts. Audiotape transcripts of whole class discussions that occurred prior to and after the three university visits (coded as Vis 1, Vis 2, and Vis 3) helped to show how the children's ideas were evolving and provided evidence to support interpretations made about the children's talking and drawing.

Findings and Discussion

During data analysis, it became apparent that the university industrial design students used a combination of talking and drawing to help the children achieve design solutions. Talking and drawing was characterized by a university student and a child working together to sift through ideas, refine their ideas, negotiate constraints, and arrive at plausible design solutions.

Design Talk

During the first visit to the university, talk was used to:

- Discuss the overall design (e.g., What need is being met? What is the function of various components? How can we understand the initial drawings?).
- Simplify the design (e.g., What can be removed? What is really important?).
- Add to the design (e.g., What should be added to address the original need?).
- Decide on specifications (e.g., Where should parts be placed? What materials could be used? What are favorite colors? What are the dimensions?).
- Explore the child's life (e.g., What are the child's likes and dislikes?).
- Explore the plausibility of the design (e.g., What is technologically possible? What cannot be built?).

After this first visit, university students generated new renderings of the children's original designs and these renderings became the focus of the second visit.

During the second visit, talk was again used to add to the design, simplify the design, and decide on specifications. New to the second visit was talk about:

- Whether the design met with overall approval (e.g., Are we satisfied with our decisions? Is this reasonable?).
- The name of the design (e.g., What will we name it?).

After the second visit, the university students revised the designs to share with the children during the third visit.

During the third visit, children with completed renderings were asked to present their ideas to the audience. In preparation for this presentation, talk centered on:

- How to describe the device (e.g., What are the important features?).
- How to use the device (e.g., How will we use this? What is the function of each component?), and if not already named,
- What to name the device (e.g., What will we name it?).

The children had great imaginations but these ideas had to be tempered by the university students' ideas about what was workable (e.g., "It is hard to tell them something is not possible." – USt 6, Vis 3; "It was difficult for the child to narrow down her ideas to something that was somewhat realistic." - USt 1, Vis 3; "The child ignored physical realities and expected things that were not very likely." – USt 6, Vis 1). Some children had to be guided to acknowledge that some design elements were not plausible (e.g., "Would it be reasonable to believe that the couch would be able to hover into space? We decided no." – USt 24, Vis 2; "She set out to think up something kind of crazy and fantastical. She was very willing to discuss those aspects of the design that were too far away from today's technology. She was agreeable to making compromises as the design progressed." – USt 24, Vis 3).

Some children added detail just for the sake of adding detail (e.g., "He had to remove some of the functions of his design to simplify it." – USt 26, Vis 1; "He sometimes wanted to add superfluous ideas." – USt 10, Vis 3), and a small minority of children had difficulty expressing ideas verbally (e.g., She was quiet and shy. She found it hard to express her ideas and she wasn't really sure what she wanted to design." – USt 18, Vis 1).

Many university students were seen to engage in a verbal iteration between the children's needs and wishes and their own adult designer knowledge (e.g., "The child decided just about everything from style, color, most functions and placement of components. I came in to give a general sense of some limitations and other needed adjustments." – USt 7, Vis 1; "All of the ideas came out of dialogue with her and I. She was very open to making suggestions and thinking up new ideas." – USt 8, Vis 2). To move forward, university students had to teach the children the language of design (e.g., perspective view). In turn, children had to teach the designers their language for describing the design and the manipulation of that design (e.g., 'diagonal' view).

Overall, talk was characterized as a social process and was used to frame the problem (What is possible? How does this connect to the child's life?), identify the needs being met by the device (What need is being met?), gain an overview of the problem space (What are we trying to solve?), help identify a variety of constraints (What cannot be built?), consider a wide range of design alternatives (What are important features?), negotiate trade-offs (What should be added or removed?), name the design, and assess the plausibility of the designs (Is this reasonable? What is technologically plausible?). Clearly, talk acted as a verbal tool that children and university students used to take design ideas forward. As one university student wrote:

> We went through different aspects of design, such as legs, doors, arms, hands, shelves, etc. This sparked new ideas. For example, we talked about a base for the shelf, then I suggested legs. This gave the child the idea of incorporating wheels on the bottom which led to the idea of having a cabinet sit on the table for you. Having him think about different aspects sparked more ideas. (USt 10, Vis 1)
>
> We talked about potential issues in problems with the design and we tried to solve them together. Discussing different options. Thinking about specific issues helped him think of solutions. (USt 10, Vis 2)

At times, the university student and the child encountered some impasse that could only be resolved through visualization on the computer or in sketches. In the next section, we discuss how drawing was also used to take ideas forward.

Design Drawing

Children made a series of initial sketches prior to their first visit to the university. These sketches showed the children's initial thoughts and were exploratory rather than representational. Although these initial sketches were ambiguous and incomplete, making them helped clarify initial ideas and gave rise to new ideas and alternatives. The time spent in the classroom on these initial sketches featured a constant interplay between "head and hands," thinking and acting.

During the work with the university students, drawing was used to transform ideas expressed in the initial sketches. The dyads spent time elaborating, refining, expanding, and developing initial ideas. Drawings showed increasing accuracy, detail, and dimensions. The final presentation drawings were recognizable representations of the finished idea and were presented in poster format (see Figure 1).

University students wrote on their questionnaires that drawing helped develop ideas in the following ways.

- Drawing helped the children to describe their own ideas (e.g., "The child also continued to draw a little bit to describe what he wanted." – USt 5, Vis 2; "We went through the child's initial drawings and I tried to understand all the little details. When I didn't understand, she would redraw them so that I would understand better." – USt 23, Vis 1).

- Drawing helped university students to describe their own ideas (e.g., “If I drew something and showed what I was thinking he would realize what I was doing and be able to add input.” – USt 6, Vis 2).
- Drawing was used to provide a visual representation of the children’s verbal ideas (e.g., “Having the child describe what she wanted in a piece of furniture but having me draw them out on paper.” – USt 5, Vis 1; “Sometimes I found it difficult to fully understand what he was describing to me. It helped to sketch things out.” – USt 2, Vis 2; “I would draw out what the child was describing to try and identify what he was trying to communicate.” – USt 9, Vis 1).
- Drawing was used to continually represent ongoing design ideas and take those ideas further along the path to completion (e.g., “Seeing the final presentation made her realize what was missing.”- USt 26, Vis 3; “The more we discussed what she had drawn, she was able to elaborate on her ideas and describe to me in greater detail exactly what her ideas were and together we came up with more details.” – USt 24, Vis 1; “The sketches I had done allowed him to see what we had discussed and having a visual allowed him to make further decisions about details and function.” – USt 10, Vis 3).

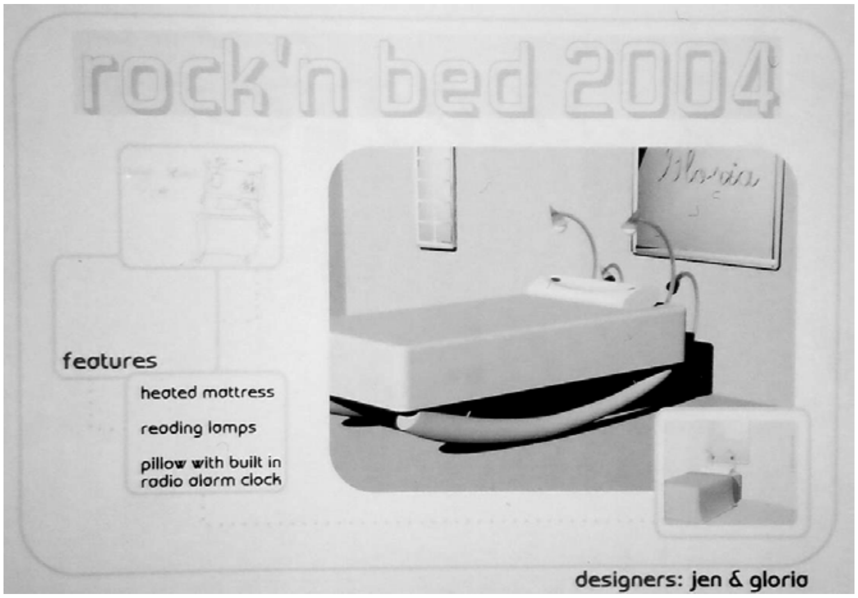

Figure 1. Example of a final poster.

Overall, drawing was characterized as a tool that could be used to generate and represent design ideas. All of the children and the university students held conversations about designing through the medium of drawing with pencils, felt markers, and computers (e.g., "Different colored pens helped better communicate different functions and materials." – USt 13, Vis 1). The children drew their ideas, university students drew the children's ideas, university students drew their own ideas, and the children drew the university students' ideas. There was a continuous representation of ongoing ideas.

Of particular interest was the role of the computer in representing ongoing ideas. Prior to the university visits, the children had minimal exposure to using a computer to draw and all but one stated a preference for using pencil and paper. At the university, however, the children appeared intrigued with the Rhino(ceros) software and the design possibilities it represented. University students wrote on their questionnaires that the computer assisted the children in the following ways.

- Visualizing in three dimensions (e.g., "He had difficulty visualizing ideas in three dimensions and the computer aided him in this sense." – USt 5, Vis 3; "Building the object in 3D space and applying color and texture allowed the child to relate better." – USt 15, Vis 1; "By bringing the design into 3D space the child was able to better communicate his ideas and become more excited and interactive." – USt 12, Vis 3).
- Showing all views (e.g., "To show them the final piece altogether and the ability to pan over the object 360 degrees in computer space." – USt 4, Vis 3).
- Trying different features and enhancing quality (e.g., "The computer allowed her to choose curves, textures, colors, etc. with ease instead of describing it to me." – USt 26, Vis; "The computer helped me to show a better quality drawing to the children and to increase their attention on what we can all do for this project." – USt 11, Vis 3).
- Giving immediate feedback (e.g., He got to see immediate shapes and let me know what he didn't like." – USt 2, Vis 3).
- Researching information (e.g., As a tool to find information and inspiration online." – USt 20, Vis 3).
- Virtual making (e.g., "It allowed us to have a final result without actually building the prototype." – USt 20, Vis 3).
- Introducing play (e.g., It aided visualization and offered an element of play." – USt 17, Vis 3; "It made the exercise more exciting, it helped to keep him interested in the task." – USt 5, Vis 3; "It made the project more fun." – USt 10, Vis 3).

In summary, the computer helped to visualize possibilities, enhanced design communication, and made it easier to move forward with an appropriate design. The computer was used together with sketches to clarify ideas and visualize the product. As one university student wrote:

> The computer helped a lot in precise, very realistic ideas and products. However, sketching helped at the initial stages to get the idea clear. The computer also enabled us to try different colors, features, materials, to see which one she liked the most. (USt 18, Vis 3).

Along with talking, drawing acted as a vehicle for design decision-making – much as both do for professional designers. Frequently, talking and drawing were interconnected. At times, when children struggled to find the words to represent their thoughts, drawing substituted for the verbal expression of ideas. At other times, drawing worked in concert with talking to clarify children's ideas, expand the range of design possibilities, and arrive at plausible solutions. As one university student wrote, "I learned how difficult it is to verbally describe ideas without visual backup. Also, how to plan and create the right questions to get a full sense of what the client wants" (USt 22, Vis 3).

Design Teaching and Learning

During the project we had to keep in mind that the children were not just engaged in a design project but in a pedagogical project. In other words, the goal was not just to design something and produce a poster but also to teach the children about design and technology. Thus, the project had both a product purpose and various teaching and learning purposes. Kimbell, Stables, and Green (1996) provide a useful way of categorizing teaching and learning purposes for design projects based loosely on the commonly used educational framework of learning goals as encompassing knowledge, skills, and attitudes.

Kimbell, Stables, and Green (1996) suggest six main teaching and learning purposes:

- Enriching content knowledge.
- Extending knowledge of the nature of technology.
- Enhancing knowledge of the nature of technology.
- Developing skills.
- Developing individual attitudes.
- Promoting group working styles.

The following examples show how each of these teaching and learning purposes was met within the context of this research project.

- Enriching content knowledge: During their talking and drawing, the university students taught the children about the key elements of design - line, shape, mass, texture, color (e.g., "We talked about viewpoints and 3D drawings. I explained what perspective view was which he called diagonal view. I also told him that if you draw something straight on from the front and sides, it can be more descriptive than a confusing perspective drawing of all the sides. I also showed him a little bit about Rhino." – USt 6, Vis 1).
- Extending knowledge of the nature of technology (design processes): The teacher and the university students helped the children learn about the importance of planning, designing, and drawing (e.g., Planning - "When

you want to create something you always need a plan. Whether it's writing or sketching, it's useful." – Ch 24; Designing - "Design means plan, create, and build. To me it seems like a process of building." – Ch 11; "Design to me means a 1D or 2D drawing that comes to life most of the time in a 3D object." – Ch 18; Drawing – "They make a rough copy and then they look back on it and see what they can improve on. Then they improve it and then they create it." – Ch 18).

- Enhancing knowledge of the nature of technology: University students taught the children that design operates within certain constraints and safety considerations (e.g., "And then if you press the button the shower will come down. Okay. Do you want to have it over here or do you want it away from … because it probably couldn't be that good to have it by the electricity." – Ch 1/USt 1, Vis 1).
- Developing skills: University students taught the children how computer graphics can help them to visually represent their design (e.g., "We just move it down a bit here. You see? So now you have a three-dimensional box on the computer [screen]. That's usually how it works." – Ch 2/USt 2, Vis 2).
- Developing individual attitudes: The children learned that much time and work is required to complete a design project (e.g., "I learned that it takes a lot of patience to make a full design." – Ch 8).
- Promoting group working styles: The children learned the benefits of collaboration (e.g., "Working with someone from the University made me proud. I really enjoyed using my Big Buddy's markers with the skinny and fat ends." – Ch 24).

In summary, the project provided children with a context in which they could learn about the complexity of design and expand their conceptual and procedural understanding of the design process – especially with respect to the role of talking and drawing in developing a plan. The richness of their interactions with the university students helped the children to contemplate their ideas and consider alternatives. In the end, the children were challenged to re-examine their ideas and assumptions and provide support for their decisions resulting in designs that told a story of the iterative and recursive nature of their work.

Implications for Classroom Practice

The original question was whether or not this study could provide some direction for design technology classes conducted in elementary classrooms. Previous discussion based primarily on the university students' questionnaire responses suggests that implications can be drawn for the kinds of talking and drawing that could be encouraged in elementary classrooms. In addition, these ideas suggest revisions to current models of classroom design.

In elementary classrooms, children's design drawing could be developed in the following ways:

- Teach children about the different kinds of design drawings and their role in generating and representing design ideas. Types of design drawings include initial sketches, ongoing drawings, and final design representations (e.g., “When I asked him to try drawing different shapes his product could be, he stayed with very simple geometric forms like triangles and circles and had difficulty imaging a similar object in 3D.” – USt 5, Vis 1; “Today I showed her a whole bunch of sketches that I created over our discussion from last time. I also had some main design sketches for her to choose from. We created a new sketch together that incorporated some more of her ideas.” – USt 18, Vis 2).
- Teach children how to draw using a variety of perspectives. Perspectives could include top, side, and magnified views of the design ideas (e.g., ; “She knew that for communication of her design to be easy, she had to draw her design in several different views.” – USt 26, Vis 3; “He liked to see the project on the computer and would have liked to manipulate it in the perspective views.” – USt 17, Vis 2). Also, if classroom projects involve the opportunity to build designs, the accuracy and completeness of the drawings can be tested by having children build each other’s designs.
- Introduce design alternatives during drawing to help children understand the importance of planning, incompleteness of plans, and the complexity of design decision-making (e.g., “The computer allowed her to see in a 3D way, the ideas that she brought to me originally. In this case, it was easier to move forward with appropriate design changes. Also, it was very simple to change color and material choices to view a number of different looks.” – USt 24, Vis 3; “I learned not always to go with your first design idea, but to think of as many ideas as possible without worrying too much about what the end result will be.” – USt 8, Vis 3).
- Direct children to draw several potential design solutions then provide a rationale for choosing one to pursue in more detail (e.g., “I would have the child come up with more than just one idea and get him to push his ideas further.” – USt 5, Vis 3; “I would push the initial concept further before we take it to completion. Give the child complete artistic control.” – USt 31, Vis 3).

Opportunities for enriching the level and extent of talk in elementary classrooms could include:

- Providing time for whole class discussions about important concepts and anchoring terms related to the design project in order to develop a language of common practice (e.g., “Some concepts they had were difficult to follow and took quite a bit of explaining.” – USt 22, Vis 1; “Questions. I can’t emphasize the importance of asking questions. It makes the child make considerations he or she never thought about. Also, encouragement is helpful. Try not to criticize their ideas unless you are following it up with perhaps a more plausible solution." – USt 16, Vis 1; "I learned the importance of asking the client a lot of questions and not expecting him to give a lot of information unless asked. I also learned that being able to draw your ideas out quickly is an extremely important skill when collaborating with a non-designer." – USt 3, Vis 3; "I asked questions in order to narrow down the most important features and how they would specifically work." – USt 24, Vis 2).

- Teacher guided conversations that assist children to think critically about design constraints (user, physical, and material), how to balance illusion with reality (i.e., what can be dreamed up versus what can actually be done), how to sift through and refine ideas, and the nature of ongoing design ideas (e.g., "He wasn't as critical as I was hoping. I thought he would say, 'I like this part of this drawing and the light and armrests on this one. Instead, he just said 'Cool! I like this chair!' and I wasn't able to determine what he liked about it." – USt 22, Vis 2; "We also talked about how we could take her initial idea – which was very 'out there'- and transform it into something slightly more practical." – USt 8, Vis 2; "We discussed what his original ideas were and then proceeded to define what features specifically achieved. We went through several steps of analyzing possibilities and weeding out those that might not be possible or useful or 'cool'. We eventually settled on a specific product with a manageable set of features." – USt 3, Vis 1; "I would try to get the child to try and communicate their ideas to me a little bit better. I did like the fact that when we communicated, we put both of our ideas together and came up with something." – USt 18, Vis 3).

The study also showed the benefits of collaborating with an older, more knowledgeable adult to reach some higher level of understanding. This finding relates to Vygotsky's notions of social cognition and the zone of proximal development (Vygotsky, 1968). Collaboration afforded the children the opportunity to expand their workable ideas and design possibilities and modeled the team approach to design seen in the profession. Children were encouraged to think outside the box, for example, to understand that designs must meet the needs of multiple users. In classrooms, collaboration tends to be with the teacher who may or may not have sufficient time available to mentor each child. To expand collaborative possibilities, teachers can arrange for children to work with students in later grades who have some design experience. Guest designers can also be invited to classrooms to talk about their work experiences and provide feedback to the children on their work.

Conclusion

The purpose of this project was to see whether pairing children with adult, novice industrial designers would reveal some possibilities for how to enrich children's classroom design technology talking and drawing. Certainly the opportunity to work with more knowledgeable adults was key to the children's experiences, but through these experiences emerged messages for teachers working with young children in design technology classrooms.

Teachers can enrich children's design technology experiences by helping children to: expand their design horizons beyond satisfying their own personal needs and wants, realize that design operates within certain constraints, place realistic dimensions on their designs, visually generate and represent their ideas on paper and perhaps with the assistance of a computer graphics program, understand key elements of design (e.g., line, shape, mass, texture, color), understand the processes of design (e.g., considering alternatives, engaging in opportunistic design), and collaborate with others.

Design technology models featured in school programs present an oversimplified view of design. Even models that emphasize the iterative and recursive nature of the design process do not capture the time and guidance children need in order to achieve thoughtful design solutions. In order to bring children closer to a more authentic approach to design, greater emphasis should be placed on how to work together to use talking and drawing as tools for thinking about design.

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Perceptions of *Technological Literacy* among Science, Technology, Engineering, and Mathematics Leaders

Mary Annette Rose

The use of the term *literacy* has a deep history within the United States as it relates to improving people's abilities to listen, read, and write using the English language. Literacy movements have employed formal and informal educational strategies with the express intent to help individuals build the core knowledge and skills of communication which help them achieve the full rights and benefits of citizenship. Over time, the term has been appropriated by numerous communities to describe a broader range of human qualities related to socio-cultural phenomena (e.g., cultural literacy), technological innovations (e.g., media, computer, and digital literacy), workplace skills, competency domains (e.g., Microsoft-literate), and curricular goals.

As early as the 1950s, the term *scientific literacy* was used in discussions of science in general education when Paul DeHart Hurd drew connections between society and scientific and technological innovation (Bybee, 1997). The term *technological literacy* was employed by C. Dale Lemons at the 1972 Mississippi Valley Industrial Teacher Education Conference (Bouhdili, in Cajas, 2001) and by James A. Hale (1972) as a fundamental focus of his dissertation research. In both instances, *technological literacy* embodied the knowledge and skills needed to function in a society dominated by technological innovation and its impact upon society. The use of this term heralded philosophical and curriculum debates (for an overview, see Zuga, 1989) where factions struggled over the mission, goals, and content of an educational program which eventually emerged as technology education.

Since the early 1990s, U.S. national leaders within technology education—William Dugger and Kendall Starkweather—have long fought to position *technological literacy* as the fundamental goal of technology education. Under the auspices of the *Technology for All Americans Project (TfAAP), technological literacy* became the embodiment of a vision for the study of technology as a general education goal for all students. The TfAAP was an 11-year, $4.2 million project (W. E. Dugger, Jr.,personal communication,

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February 20, 2006) administered by the International Technology Education Association (ITEA) and funded by the National Science Foundation and National Aeronautics and Space Administration (NASA). In its premier document, the TfAAP presented a rationale for the study of technology to a national audience (ITEA, 1996). Then, after several years of consensus-building strategies, the TfAAP released the *Standards for technological literacy: Content for the study of technology (STL; ITEA, 2000)*. These content standards were meant "to build the case for *technological literacy* by setting forth precisely what the outcomes of the study of technology should be" (p. 3). Within this document, *technological literacy* is defined as "the ability to use, manage, assess and understand technology" (p. 7).

The T*fAAP* has been one of the most far-reaching curriculum reform projects to occur within technology education. Its national impact can be attributed, in part, to the multi-disciplinary representation of its advisory board, consensus-building methods used for decision-making, and the efficacy of its approach to curriculum change. After more than a decade of advocacy for the goal of *technological literacy*, there is evidence to suggest that this vision has diffused throughout certain sectors of the technology education profession. For instance, Daughtery's (2005) study of technology teacher educators indicates widespread support for 18 of the 20 content standards.

However, the extent to which other educational communities share common values and definitions for *technological literacy* has not been established. Lewis and Gagel (1992) point out, "advocacy for the goal of technological literacy originates from philosophically diverse quarters (e.g., the scientific community, business and industry, politicians) and it cannot, therefore, be assumed that the concept has a stable, unambiguous meaning" (p. 117).

In addition, there have been urgent political voices and significant financial investments—$2.8 billion in fiscal year 2004 for 207 education programs (Government Accounting Office, 2005)—to improve opportunities for all students to attain high standards of achievement in science, technology, engineering, and mathematics (STEM). These efforts are driven by a desire to maintain the technological competitiveness of the U.S. into the future and address a need for teachers to build deep understandings of mutually relevant STEM concepts and processes. Therefore, it could be argued that achieving common ground among key stakeholders embedded within STEM education—teachers, teacher educators, curriculum developers, and professional organizations—is a precondition to envisioning and implementing curricular programs that could positively impact the *technological literacy* of their students and possibly the competitive strength of the U.S. workforce.

Purpose and Research Questions

The purpose of this research study was to gauge the extent to which a vision of *technological literacy* might be shared among leaders of the STEM communities. Three research questions originally posed by the leadership of the

Mississippi Valley Technology Education Conference guided the study, including:

- What are the perspectives of *technological literacy* in each of the four STEM education areas?
- To what extent is *technological literacy* an important goal in each of the STEM education areas?
- To what extent can technology education lead STEM education in delivering on the goal of general *technological literacy*?

Methods

This descriptive study was a re-telling of perspectives and experiences garnered through semi-structured telephone interviews with 13 leaders of national educational organizations during the fall of 2006.

Participants.

Four organizations were selected as exemplars of professional organizations that support educators within the STEM disciplines because of the size of their membership, their charge to support undergraduate teacher education, their leadership in developing national educational standards, or their involvement in STEM programs. These include the National Science Teachers Association (NSTA, *n* = 2), National Science Education Leadership Association (NCELA, *n* = 3), the National Council of Teachers of Mathematics (NCTM, *n* = 3), and the American Society for Engineering Education (ASEE, *n* = 5). The technology education community was purposefully excluded from this sampling frame because both the researcher and the target audience were professionally embedded within the technology professional community.

After receiving human subjects research approval, potential informants were purposefully selected from each organization because of the leadership position individuals held within the organization. Specifically, members of the board of directors, and committee chairs, especially those officers related to *technological literacy*, standards, teacher education, or K-12 education, were invited to participate in the study through a personal telephone invitation.

Interview Protocol

After an explanation of the purpose of the study and assurances of confidentiality, these key informants engaged in telephone interviews lasting from 25 to 75 minutes. A set of 20 questions (14 open-ended) guided each interview; additional probes were extended to better explore unique propositions and unexpected issues.

Initially, open-ended questions elicited individual "points of view" on several topics, including characterizations of technology and *technological literacy*, examples of how STEM curricula addresses technology and technological literacy, familiarity with the STL, and receptiveness to interdisciplinary partnerships. In addition, several closed-ended questions helped clarify informants' judgments about established definitions or principles held by the technology education community. For example, modeled after an item on the 2004 ITEA/Gallup poll (Rose, Gallup, Dugger, & Starkweather, 2004), participants were asked: "Using a broad definition of technology as 'modifying our natural world to meet human needs', does __[insert STEM]__ education address the study of technology? If so, how …"

Data Analysis

To minimize interpretive bias, the researcher recorded verbatim the conversations with informants and reviewed single transcripts in their entirety before segmenting the data by STEM area and research questions. As noted in the Findings and Interpretation section, inductive (themes emerging from the data) and deductive (themes pre-established) analytical methods were employed for coding and interpreting the narratives. Key documents referenced by these informants were also reviewed in order to enhance the consistency of information and explicate the interview data.

Findings and Interpretation

Clearly the limited number of informants, the methods of data gathering, and the analytical lens of the researcher limits the transferability of these results. Any judgments about the usefulness of these findings must be made by the reader. These findings are presented below as they relate to the guiding questions.

What are the perspectives of technological literacy in each of the four STEM education areas?

Several questions specifically elicited informants' understandings of technology and *technological literacy*. In Table 1, key phrases have been extracted from the responses of the informants when asked: In the context of _[insert STEM]_ education, what does 'technology' mean?" This table represents a simplified facet of the results of an inductive process used for coding the data by emergent themes and then collapsing themes into a manageable set. When considered together these themes represent the range of perspectives offered by the informants. When examining specific phrases, it should be noted that this tabular representation indicates overlaps across themes. These themes included: knowledge of technology, technology as the object of assessment, technology and society, technological processes (design and problem solving), technology for teaching and learning, and technology as artifacts or outcomes.

In Table 2, key phrases represent informant's responses when asked: "In the context of _[insert STEM]_ education, what does 'technological literacy' mean?" Using a deductive analytical method, this data was categorized into the common themes extracted from the *STL* in order to more easily compare these perspectives to those of the technology education community. In addition, two categories have been added to represent other comments offered by the informants, including educational technology.

Table 1
Perspectives on the meaning of technology from STEM informants.

	Science	Engineering	Mathematics
Knowledge about Technology		Understanding, handling, & properly using anything that humans synthesize	
Technology as Object of Assessment	Actual physical stuff, how to use it, & evaluate it Evaluating & selecting tools & materials		
Technology, Individual, & Society	If a human need is to know & understand & explore, then technology certainly meets that human need. It would be defined by human need		
Technological Processes: Engineering Design, Trouble-shooting, R&D, Problem Solving	Retrofitting modern concepts into structures A way of problem solving. A way of logically thinking through a problem to find a solution Design engineering	Habits of mind, processes, tools, materials, & ways we approach the human-built world ….design under constraint & optimization	
Technology for Teaching or Learning	Use of tools as it applies to science teaching Technologies enhance instruction Enable students to do experiments, manipulate variables & find information Technology enables long distance learning Instructional technology		Tool for the study of math Visual tools that open doors to mathematics at higher levels Application of technology to teaching Appropriate use of technology for doing math

Table 1 (continued)
Perspectives on the meaning of technology from STEM informants.

	Science	**Engineering**	**Mathematics**
Technology as Artifact or Outcome	Technology is a tool The software & hardware of technology That which grows out of science Monitoring environmental conditions	Systems that are engineered, designed, or created to achieve a purpose Outcomes of the engineering process Computational technology, software for computers, graphic calculators The human built environment Products of the engineering profession	Any kind of device that aids you in doing something: a calculator. Handheld technologies

A multiple-answer question was also posed to informants; this item encouraged informants to select any combination of established definitions which spoke to their understanding of *technological literacy*. Column 1 of Table 3 represents the distribution of selections by STEM discipline.

Science

The science informants offered the most multifaceted and complex definitions for *technology* and *technological literacy*. The initial definition offered by the majority of informants was "technology as tool/tool use", especially as it related to teaching, learning, or doing inquiry. For example, one informant offered this example:

> We use technology for monitoring environmental conditions. Without the instrumentation, we could not track environmental conditions in an effective manner.

In addition to defining technology as a tool/tool use, science informants described technology in terms of connections to the individual and society, design and problem solving processes, and as an object of assessment. These connections were evidenced in thoughts about *human need, retrofitting, problem solving, engineering design, and evaluation and wise selection.* An informant's reference to the *Science for All Americans* (AAAS, 1989) document further elaborated this theme. Essential propositions in the Nature of Technology section note that technologies have side effects and risks, and they

Table 2
Perspectives on the meaning of technology literacy among STEM informants.

Technology	Science	Engineering	Mathematics
STL #1-3 • Characteristics • Core concepts • Relationships	Meeting the ITEA standards Understanding the manmade [sic] world from the natural world	Understand the important underlying principles that engineers use to create technology	Minimal level of knowledge about tools & systems Read, write, & comprehend text
STL #4-7 • Effects • Environment • Role of society • Influence on history	The safety piece, the technology that we need to ensure the safety of students & the students in the broad society Science, technology, & society		
STL #8-10 • Attributes of design • Engineering design • Role of troubleshooting, R&D…. problem solving	Applying that knowledge [conceptual science] to address a problem whether it is a medical, physical, or environmental problem Important in using technology & as consumers telling the difference between hype & what it is actually doing Using technology to solve everyday problems Experiencing low-tech & high-tech tools	Know key principles that engineers use, including both design principles & engineering science Every individual needs to have habits of mind, knowledge & the ability to solve problems Ability to effectively use technology either in the workplace or for personal benefit Being comfortable with technology, understanding, handling, & properly using anything that humans synthesize	
STL #11-13 • Apply design process • Use & maintain • Assess			The ability to solve [problems] & do one's work Understand & use basic technology

Table 2 (continued)
Perspectives on the meaning of technology literacy among STEM informants.

Technology	Science	Engineering	Mathematics
Other	A teacher would understand the use of a wide variety of tools, when & how to apply Teachers know how to integrate technology & enhance their teaching Students are technologically literate Meeting the ISTE standards	I don't know	I don't know. We don't talk about it

Table 3
Results of STEM informants' selection of definitions for technological literacy.

Respondents	I'm going to read four definitions. Which of these describes your understanding of a "technologically literate" person? (multiple answer)
SEEE	a. A person who is able to read and interpret literature about technology.
SSSEEE	b. A person who is able to design, build, install, and troubleshoot products and systems.
SSSEEEEEM	c. A person who critically examines technological innovation in order to make informed decisions.
SSSSSEEEEM	d. A person who understands linkages among the individual, technology, environment, and society.
M	e. Other (Using technology to solve everyday problems)

Key: S=Science (n=5), E=Engineering (n=5), M=Mathematics (n=3)

can fail, therefore decisions about the use of technology are complex at both the societal and personal levels (p. 44). Furthermore, this perspective places the analytical (e.g., risk analysis) and decision-making acts prior to the introduction of the innovation or instantiation of the design. Assessment that precedes technological adoption can inform adoption and diffusion decisions. This chronological placement may also differentiate the science definition of technology from that portrayed within the technology education literature where the emphasis is upon assessment of an innovation after its implementation (see STL #13).

Among the definitions offered by science informants, there were strong parallels between definitions of *technology* and *technological literacy*. As indicated in Table 2, the range of responses addressed:

- understandings of the manmade [sic] world;
- connections among science, society, the environment, and technology;
- abilities to use technology, especially in learning and teaching science and conducting inquiry;
- abilities to evaluate and make informed decisions; and
- standards for technological literacy, including both those produced by the ITEA (2000) and the International Society for Technology in Education (ISTE, 1998).

Science informants offered examples of how science and technology seem to be interdependent. An informant explained that biotechnology (as a course of study) is being adopted by many larger districts in her state. However, within the biotechnology field, the boundaries between science and technology are blurred. The technology enables scientists to research gene splicing and stem cell research, but the tools and processes required to do this research often have to be developed for this research to continue.

Agreement was also unanimous among the science informants that a technologically literate person was one who understands linkages among the individual, technology, environment, and society (Table 3). However, the majority of respondents also insisted that a single statement could not encapsulate the full range of knowledge and abilities that they associated with the term. One informant proposed that it takes both the *STL* and the *National Educational Technology Standards for Students* (ISTE, 1998) to elaborate what it means to be technologically literate in grades K-12. Certainly, it must be concluded that the science informants hold a broad perspective of *technological literacy* which emphasizes a knowledge base, assessment, decision-making, problem solving, and its interconnected nature to society.

Engineering

As shown in Table 1, engineering informants defined technology along several facets: technology as artifact or outcome, knowledge about technology, and processes. The strongest sentiment was that technology was an outcome, artifact, or creation of an engineering process, rather than as a tool to accomplish engineering design or as the process of engineering. Explanations offered by two informants may help clarify this perspective:

> Tool use makes me think of technology and not engineering. It's engineering if there is a direct linkage from the knowledge base to the solution of a problem. I've heard people from technology education speak about a technological design process or a technological problem solving process. This is never

> mentioned in engineering. Engineers would reject the notion that you do technology.

In addition, the reaction of two informants to a definition of technology—"modifying our natural world to meet human needs"—offered to elicit responses to research question #2 was also informative. One rejected this definition of technology because of its engineering orientation; he explained that this "definition seems to be the creation of technology" not a definition of its meaning. Another informant spoke to the inadequacy of the definition: "this definition is lacking because it doesn't focus upon constraints and optimization." At the very least, this line of evidence suggests that the language employed by the technology and engineering education communities may present obstacles to developing mutual understandings about *technological literacy*.

Perspectives of *technological literacy* among the engineering informants were fairly consistent with clear connections to the framework of "knowledge, capabilities, and ways of thinking and acting" that the Committee on Technological Literacy presented in *Technically Speaking* (NAE & NRC, 2002). In addition, all engineering informants agreed that a technologically literate person may be described as one who has the ability to critically examine technological innovation in order to make informed decisions. This emphasis upon critical thinking and decision-making is mirrored in the National Academies recent effort to examine approaches to assess *technological literacy*. In *Tech Tally* (NAE & NRC, 2006), the Committee on Assessing Technological Literacy renamed the "ways of thinking and acting" dimension to "critical thinking and decision making" to better represent one's approach to technological issues (p. 2).

These informants were also quick to indicate that "engineers are far more technologically literate than the average citizen. However, their *technological literacy* is not equally balanced across all the aspects." One informant explained:

> There is a difference between a professional [engineer] and a technologically literate citizen; the professional has more advanced skills. But it's also important that a citizen has similar literacy especially as it applies to medical technologies and communication systems. Just because you are an engineer does not mean that you could lay claim to a domain outside your specialized area. I wouldn't expect an electrical engineer to be more literate than an average citizen in regards to cloning.

Mathematics

As suggested by Table 1, all mathematics informants restricted their definition of technology to tools, especially those used to teach, learn, and do mathematics. When offered a broad definition of technology—"modifying our natural world to meet human needs"—one mathematics informant explained:

> We don't use those phrases. We talk about the appropriate use and application of technology [as it applies to mathematics], not the technology itself…. Mathematics is used as a tool to modify the natural world. Technology is a tool

> within that tool set…. We have three principles which are outlined in our standards.

A review of the *Principles and Standards for School Mathematics* (PSSM; NCTM, 2000) confirmed this perspective. In this national standards document, one of these principles stated:

> Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances students' learning. (Principles for School Mathematics section)

Additionally, informants indicated that technology is also woven into mathematics through the communication, representation, and connections threads of the PSSM content standards. Although a review indicated that explicit references to technology were scarce within these threads, one infers that technology is valued as a tool for developing, sharing, visualizing, and demonstrating mathematical understandings. For example, one respondent explained that technology "represents ideas using different forms, such as physical forms, graphs, data, and symbolic forms."

In contrast to their narrow definition of technology, mathematics informants' perspectives on *technological literacy* were broader and more encompassing. As evidenced by Table 2 and 3, it appeared that the literacy connection spoke to the development of "minimal skills" that enabled people to make informed decisions about both the problems encountered in everyday life, as well as future "opportunities and challenges" encountered by society. An informant elaborated this point:

> For us, the ability to simulate future scenarios, see *Illuminations* on our Web site, allows students to explore and control future pandemics, population, the possibility of catching a disease, and the number of days a person is contagious and quarantined…. I contend this is technology.

Given these perspectives, we may conclude that *technological literacy* refers to a minimal set of understandings and skills used to explore, predict, and make more informed decisions about personal and societal problems.

To what extent is technological literacy an important goal in each of the STEM education areas?

In addition to more general discussions, informants were asked: "Technological literacy is sometimes defined as 'one's ability to use, manage, assess and understand technology.' In light of this definition, is developing technological literacy among students an important element in _[insert STEM]_ education?" As indicated in Figure 1, informants responded using a 4-position scale, ranging from Very Important to No Importance. However, these responses cannot be interpreted on an equal interval scale because there were qualitative differences in their definitions of *technological literacy* and the examples respondents offered to describe the position of technological literacy within their educational area. Further discussion will be offered for each STEM area below.

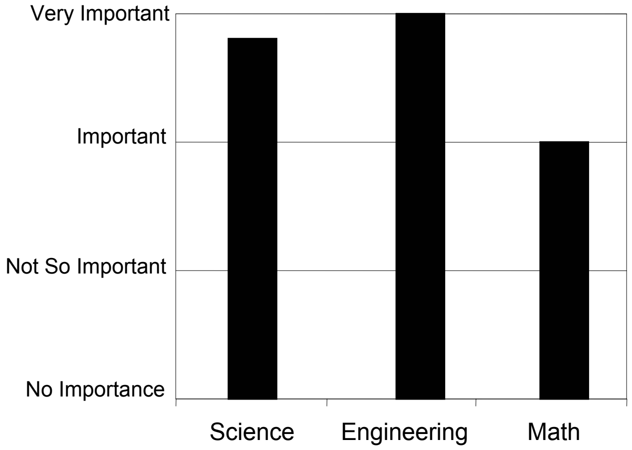

Figure 1. Reported importance of *technological literacy* to STEM informants.

Science

Most evidence from this inquiry supports the conclusion that the science informants link *technological literacy* to science literacy. Informants' numerous references to *Science for All Americans* (AAAS, 1989) and the *National Science Education Standards* (NSES; NRC, 1996) further clarified these connections. There is a clear and redundant message within these documents that building both science literacy and *technological literacy* among all people is an urgent national concern for the health and well-being of citizens, the environment, and the economy. A review of the NSES revealed explicit standards and explanations related to these connections; for instance, Content Standard E states:

> As a result of activities in grade 9-12, all students should develop:
> - Abilities of technological design
> - Understandings about science and technology (p. 190).

Therefore, a reasonable conclusion is that the goal of *technological literacy* is an essential element to the study of science. As one informant emphatically stated:

> Technological literacy is critical…The whole notion of learning science conceptually is to apply that knowledge to a model that will address a problem whether it is a medical, physical, or environmental problem.

Engineering

Although all engineering informants indicated that *technological literacy* was very important to engineering education (see Figure 1), three of five informants cautioned that their views were probably not representative of all engineering educators. One informant conceded "engineering students need to develop *technological literacy*. But they are not necessarily getting it from the engineering curriculum." For instance, when asked where an undergraduate engineering curriculum might provide experiences for students to make connections between engineering and societal concerns, a second informant positioned within a prominent engineering institution indicated that these connections were limited to two experiences within the undergraduate curriculum. These connections were made within a seminar and a senior design project where ethical considerations of the project must be taken into consideration.

However, engineering informants enthusiastically reported that there were significant efforts within the ASEE to raise the consciousness of its members toward *technological literacy*, including the technological literacy strands of the 2005 and 2006 ASEE National Conferences and the formation of a Technological Literacy Constituency Committee. One informant explained:

> The Technological Literacy Constituency Committee has been in existence for less than 2 years. One of our goals is to define technological literacy relative to engineering education. Our goal is to become a full Professional Interest Council within the ASEE. To do that, our committee needs active members. We invite involvement from technology educators and the ITEA.

There was a common sentiment that other populations of learners should also engage in engineering design activities throughout their educational career. Informants spoke enthusiastically about current efforts to infuse engineering into the K-12 environment (e.g., Massachusetts Department of Education, 2001) especially through access to resources provided by the ASEE K12 Engineering Center (see http://www.engineeringk12.org/). In addition, one informant explained that there was a small, but dedicated group of engineering faculty across the U.S. who delivered undergraduate courses which aimed to build technological literacy among non-engineering college students (see Krupczak & Ollis, 2005, for examples).

Mathematics

All mathematics informants indicated that *technological literacy* is important within mathematics education. As already discussed, the mathematics informants' narrow definitions for *technological literacy*—skills and abilities related to teaching, learning, and doing mathematics to solve problems—tempers the weight we should place on their contention that *technological literacy* is an important goal within their area. An informant's reaction to definitions of *technological literacy* clarifies this point:

> I don't see this as math education. I don't believe that building technology literacy, the way you have defined it, is a part of mathematics education.

Therefore, we must conclude that building *technological literacy* is not as high a priority within mathematics education as Figure 1 suggests.

To what extent can technology education lead STEM education in delivering on the goal of general technological literacy?

To approach this highly-speculative, politically-charged question, several assumptions had to be made. First, it was assumed that familiarity with technology education as a school subject, the STL, and professional organizations for technology educators (e.g., the ITEA) would be a necessary precondition for members of the other STEM areas to accept leadership from the technology education field. Second, it was also assumed that confidence in a potential leader could be inferred from recommendations informants make about how public schools should build *technological literacy* among students and about what entities should lead a national effort.

Familiarity

To assess familiarity, a specific question was raised concerning informants' level of familiarity with the STL. Informants responded using a 4-position scale, ranging from Very Familiar to Not Familiar At All. As indicated by Figure 2, all communities had awareness-level familiarity of the STL; in other words, informants knew this document existed but could not discuss its general themes or attributes. In addition to this direct question, a phrase count of the occurrences of technology education or any technology professional

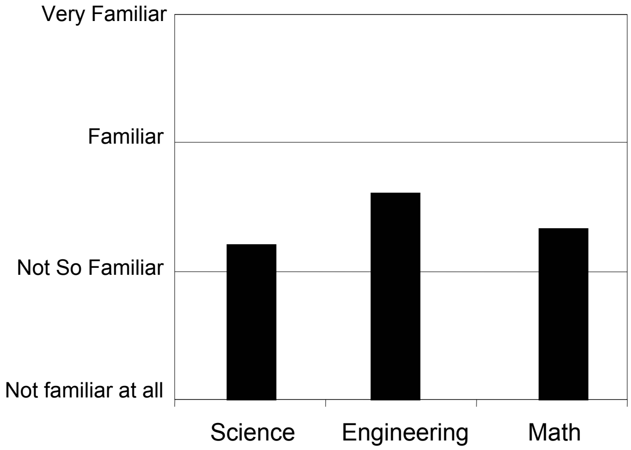

Figure 2. STEM informants' familiarity with *Standards for Technological Literacy* (ITEA, 2000)

organization within the informant's responses was conducted. The results indicated that references to technology education as an area of study were negligible, with only one reference made by science, and five made by engineering informants. References to a technology education professional organization, only the ITEA, occurred more frequently with two from science and six references from engineering informants.

Confidence in School Curriculum

To assess levels of confidence that STEM informants might have in technology education as a curricular program, informants were asked to make recommendations about how public schools could best build *technological literacy*. Six of thirteen informants recommended that public schools make it a responsibility of all subject areas within a school. Not one informant suggested that the appropriate placement of *technological literacy* goals should be embedded within technology education or a technical subject area. Two engineering informants provide some insight into this reasoning:

> I would like to say that all students would take an interdisciplinary course in technological literacy. But, that's not going to happen. Schools should integrate the study of technology into science and math because all students must take science and math. Then in high school, students can take specific explorations of technology and engineering in their electives. The focus of my high school experience was a college prep orientation. This program [technology education] sounds more like a vocational orientation. I do think that some courses that are directly oriented toward understanding or using technologies can be a useful thing. But I suspect that there isn't that much linkage between the more traditional math and science courses. Engineering is a linkage between the two.

Confidence in Leaders

Finally, informants were asked to make recommendations as to who should best lead a national effort to deliver on the goal of *technological literacy*. Twenty-one recommendations were offered; the most frequently mentioned organizations are mentioned below with first letter codes representing each community, (e.g., S=Science):

SSSSE	National Science Teachers Association
EEEE	American Association of Engineering Education
EEE	International Technology Education Association
SE	National Academy of Engineering

Leadership Conclusion

Given the science and mathematics informants' (1) low level of awareness of the STL and the technology profession, (2) lack of confidence in technology education's power to build technological literacy in public schools, and (3) recommendations for desirable national leaders, one might predict that any entity or professional organization embedded within the technology community will have a significant struggle in positioning itself as a national leader within science and mathematics. However, there appears to be an opportunity for mutual cooperation between technology education and the engineering community.

Conclusion

This descriptive research study characterized and compared the perceptions of *technological literacy* among 13 leaders of professional organizations representing science, engineering and mathematics communities. The evidence suggests that these STEM leaders conceptualize it in subtly different ways and place priority upon different dimensions. The science informants tend to value the knowledge and abilities that enable them to conduct inquiry, solve problems, evaluate, and make wise decisions about technology within a larger social context. The engineering informants value the knowledge and abilities that enable them to apply engineering design in a human-synthesized world. The mathematics informants value technological knowledge and skill that enables them to understand and use technology to do and teach mathematics, as well as to make more informed decisions about personal and societal problems.

The importance of *technological literacy* as a goal of STEM education varied among the STEM informants. The interdependencies among the knowledge, abilities, and habits of mind expressed within science literacy and *technological literacy*, as well as the multiple, explicit connections made within the *Benchmarks for Science Literacy* (AAAS, 1993) and content standards (NSES) indicate that the science community places high priority upon *technological literacy*. The engineering informants also value *technological literacy*, especially as it relates to the knowledge and abilities which enable them to engage in their fundamental professional act of engineering design. However, their interest in making *technological literacy* a goal is still emerging and appears to parallel a movement to infuse engineering into K-12 education. The mathematics informants place high priority upon a subset of *technological literacy*, i.e., the abilities and knowledge required to teach, learn, and do mathematics to solve problems. This evidence is in clear agreement with Lewis and Gagel's (1992) conclusion that "technological literacy as a general educational goal cannot be claimed by any one sector or discipline within the curriculum. The sum of the conceptions of technological literacy we see results in an amalgam which suggests a whole-school approach to the problem" (p.135).

These STEM leaders did not readily associate the "T" in STEM with a curricular program known as technology education. Among those who were aware of technology curricular programs, there was a lack of confidence in its power to positively build *technological literacy* among students. There was a prevailing sense that technology education was not considered to be an equal partner in efforts to build interdisciplinary knowledge and skills at the public school level in order to increase numbers of students pursuing undergraduate studies in STEM disciplines. Therefore, this evidence suggests that science, engineering, and mathematics communities may not look toward the technology education profession for leadership.

Although there have been significant political, economic, and educational efforts to promote a common understanding of *technological literacy* among STEM educators, the goal still remains illusive and the costs of achieving common ground may be great. It may be time to call into question the assumption that the technology education field is the banner waver of *technological literacy*. Fundamentally, technology proponents may be wise to embrace diverse representations of *technological literacy,* applaud the significant efforts of others, welcome collaboration with others, and focus attention on the unique contributions they make in building *technological literacy* within general education.

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Engineering Modeling Using a Design Paradigm: A Graphical Programming-Based Example

Paul D. Schreuders

Introduction

Engineers combine design paradigms or methods for problem solving ("OED Online", 2004) with mathematical modeling techniques to predict the success of their designs, a method that they have found to be accurate and repeatable. However, computer models are not just used in traditional engineering design and practice. Many computer games have complex mathematical models hidden behind their interfaces. Beyond the obvious examples, such as the Sims™ and SimCity™, the "first person shooters" contain extensive physics models, so that thrown objects and jumping characters behave correctly on the screen ("Best of What's New 2005", 2005; Tamaki, 2006; Terzopoulos, 1999).

As engineering has moved into the biological arena, engineering modeling has been used to describe living processes through the creation of constructs that reproduce, move, and eat. The reverse is also true. Modeling has adopted into its array of methods for solving problems, biological approaches such as neural networks and evolution-based optimization (Kim & Cho, 2006; Terzopoulos, 1999).

Mathematical models are also becoming increasingly important in the workplace. Businesses use models to optimize their future plans. Brokers use models to identify when to buy and sell stocks. Actuaries use models to predict death rates for insurance companies. Biologists use models to predict the impact of changes to the environment (Gotelli, 1998; Kurzweil, 1999).The teaching of model development is primed to move into the high school classroom for several reasons. These reasons include the removal of barriers to modeling, the inclusion of modeling in national curricular standards, and the adoption of pre-engineering curricula by many high schools.

First, many of the barriers to teaching modeling have been removed. As the computer gaming industry has demonstrated, the hardware for modeling is both

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available and affordable. Further, analyses such as Moore's Law indicate that computer hardware will become exponentially faster for the reasonable future (Kurzweil, 1999). The software required to create these models has also matured and become easier to use.

Second, modeling integrates technology education, science education, and mathematics education by linking the design standards from the *Standards for Technological Literacy* (ITEA & TAAP, 2000) and the *National Science Education Standards* (National Research Council [U.S.], 1996) with the mathematical modeling standards of the *Principles and Standards for School Mathematics(*National Council of Teachers of Mathematics*, 1989)*.

Finally, there is a continuing trend towards the adoption of engineering design into the high school curriculum. Project Lead the Way, for example, has over 1300 participating schools in 45 states (PLTW, 2006). This trend is evident with the development of the *Standards for Technological Literacy: Content for the Study of Technology* (STL) and its endorsement by William A. Wulf, former President of the National Academy of Engineering (ITEA & TAAP, 2000). Engineering design emphasizes analysis and modeling. The development of student appropriate methods for engineering analysis represents some of the biggest remaining challenges in bringing engineering design into the high school. As shown in Table 1, there are a number of ways that analysis has been approached.

Table 1.
Some current practices for performing engineering analysis in the high school classroom.

Methodology	Limitation
Student computation	Restricted by the students' mathematical background; often limits the problems to those soluble by algebra or trigonometry
Use of tabular or graphical data	Student solutions are limited to those considered in advance of the project
Use of software (pre-programmed)	Student solutions are limited to those considered in advance of the project
Student written software	Requires extensive class time to teach programming/write the software; restricted by the students' mathematical background
Experimental/trial-and error	Inefficient in creating designs; students often fail to understand the science and technologies behind their design; time consuming
Graphical modeling	Requires modeling software; Unfamiliar to most technology teachers

There is a tendency to consider engineering design paradigms as primarily applicable to the creation of physical objects or, perhaps, software. A more appropriate view, however, is to view the design process as a paradigm for problem solving with the goal of creation. Historically, this paradigm has been amazingly effective for the creation and implementation of new ideas and inventions. It is used for the identification of the boundaries of possible designs and for the elimination of impossible, impractical, inefficient, or otherwise undesirable designs. A number of design paradigms have been developed for use in the classroom (Eggert, 2004; Gomez, Oakes, & Leone, 2004; Haik, 2003; Oakes, Leone, & Gunn, 2004). In general, these paradigms differ only in minor ways. One of these paradigms is shown in Table 2. The design process includes a series of tradeoffs that alter what is considered the optimal product. There may, in fact, be multiple optimal designs (Koen, 2003). The adoption of the design paradigm for model development has an advantage in that it is a process with which technology educators and their students are familiar and proficient in using, allowing the transfer of existing skills. It provides a useful, structured approach to introducing engineering analysis into the classroom, a goal and a challenge for many pre-engineering programs.

Table 2.
A comparison of two design paradigms, showing a general design paradigm and the same paradigm adapted for use in graphical modeling.

Stage Number	**Design Paradigm** (Gomez, Oakes, & Leone, 2004; Oakes, Leone, & Gunn, 2004)	**Modeling Paradigm**
Stage 1:	Identify the problem/product innovation	Identify the system to be analyzed or simulated
Stage 2:	Define the working criteria/goals	Identify the information to be obtained from the model
Stage 3:	Research and gather data	Research and gather data
Stage 4:	Brainstorm/generate creative ideas	Brainstorm/generate model structures
Stage 5:	Analyze potential solutions	Develop and refine model structures
Stage 6:	Develop and test models	Implement the model
Stage 7:	Make the decision	Specify and simulate
Stage 8:	Communicate and specify	Interpret and communicate
Stage 9:	Implement and commercialize	Protect and commercialize
Stage 10:	Perform post-implementation review	Perform post-implementation review

Until recently, modeling required significant programming expertise and/or the knowledge of differential equations in order to analyze dynamic systems (Coughanowr & Koppel, 1965; Lewis & Yang, 1997; Ogata, 1997). However, with the maturation of graphical modeling software, this is no longer true. In this article, a design-based approach to engineering model development will be examined. Graphical approaches emphasize the development of a model's structure prior to its implementation.

Graphical Modeling Software

In graphical modeling software, programming is performed by manipulating graphical elements and their connections. Educators familiar with using RoboPRO ("ROBO Pro", 2005) or Robolab ("Robolab", 2004) to control robots will find that the techniques used in graphical modeling software are quite similar. In addition, because of their emphasis on model structure and minimal programming requirements, graphical modeling software allows the development and solution of complex mathematical models rapidly with limited mathematical background.

A number of engineering-specific graphical modeling software packages exist. However, because they presume significant discipline-specific expertise and are expensive, these packages are not useful in the high school classroom. Fortunately, a number of generalized modeling packages exist, including Simulink ("Simulink", 2005), Berkeley Madonna (Zahnley, 2006), and Stella ("Stella", 2005). Simulink is the most powerful of these packages, but the least friendly to the student user. Stella is the least powerful package, but is by far the most student friendly. Madonna lies somewhere in between the other two. All three packages are available with academic discounts at prices ranging from $50 for a single copy to a site license for around $1000.

Mathematical models of dynamic systems contain variables known as "state variables." These variables and their inflows and outflows are described by sets of first order differential equations (Ogata, 1997; Phillips & Harbor, 1996). The solution to the model is obtained by simultaneously solving these differential equations. The flows are described using flow rate coefficients, equations, etc. (Hannon & Ruth, 1997; Richmond, 2004). In graphical programming software, all of the above information is entered using a graphical interface. Then, hidden to the user, the software solves the differential equations, using one of several numerical integration methods.

In practice, the link between a graphical description of a system and the graphical program of the systems is clearest for classes of problems where each state variable represents a reservoir of things and the things flow between those reservoirs along defined pathways. Some examples of this type of systems include movement of liquid between tanks, storage, movement and distribution of energy in an automobile, and movement of money through a business. Techniques for converting equations directly into graphical programs are available (Ogata, 1997). However, the resulting graphical programs often bear little resemblance to diagrams of the physical system, making them more challenging to use in the classroom.

The clearest way to show the benefits of graphical model development is using an example. This article will model the spread of a computer virus through a school's computer laboratories. The most obvious benefit of such a model is as an aid to developing strategies for combating computer virus infection, reducing the cost to companies and individuals. Models of a computer virus infection can also examine a computer network's vulnerability to disruption and suggest possible areas for improvement.

Stella software will be used herein to create the model. However, any of the generalized graphical modeling software packages could be used. Educators will find that Stella requires a minimal amount of instruction (typically on the order of a few hours) for students to develop basic facility in its use. In addition, a wide range of problems have been solved using this software, so that grade appropriate problems are available in both the scientific literature and in books (Fisher, 2005a, 2005b; Hannon & Ruth, 1994, 1997; Richmond, 2004).

The Virus Model's Development Process

This paper will develop and demonstrate an approach to modeling using a ten-stage modeling protocol, adapted from engineering design protocols (Gomez, Oakes, & Leone, 2004; Oakes, Leone, & Gunn, 2004), to model the spread of a computer virus. The design model paradigm is shown in Figure 1.

Stage 1. Identify the system to be analyzed or simulated

In system identification, the model's contents are chosen and extraneous content is eliminated from the model. It has several aspects. The first is identification of what system is to be modeled and what components of that system are to be included in the model. As part of this, the nature of the system needs to be analyzed. An important component of this analysis is the isolation of the root process to be modeled. In this example, the behavior of the virus is the root process. The brand of operating system is relevant only if it alters the system's behavior. The next important aspect of system identification is the definition of the system's scope and resolution, i.e., what will *not* be modeled. For example, in this example, the Internet will not be considered. In addition, the network speed will not be considered, since it operates at speeds that are orders of magnitude faster than the processes being modeled.

Identification of the system for this example must consider the three main categories of computer viruses: file infector viruses, boot-sector viruses, and macro viruses (Kephart, Sorkin, Chess, & White, 1997). The greater majority of known viruses belong to the first category, infecting application files such as games, spread-sheets, and word processors. The second category, boot-sector viruses, reside with the start-up information executed when a computer first starts up. Once in place, a boot-sector virus can infect any electronic storage media used on that computer. Many computer applications today allow the program to run macros or scripts, which are small sub-programs used to perform

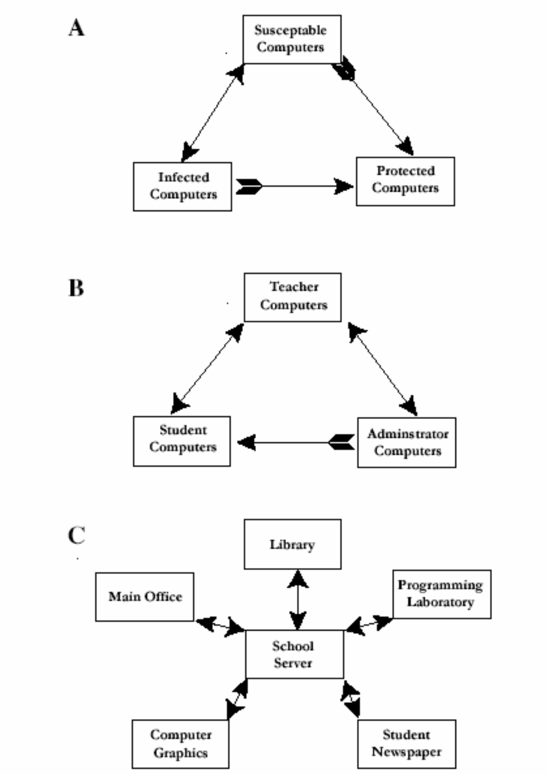

Figure 1. A graphical depiction of some possible approaches for grouping computers in a computer virus model. The computers have been grouped by virus infection status (A), user type (B), and location (C).

repeated actions or a series of actions quickly. The final category of viruses, macro viruses, infect the data files that are freely and rapidly shared by users. A data file infected with a macro virus will execute a viral macro script in response to the actions of the user. These are the most prevalent of all viruses (Kepschreudersphart, Sorkin, Chess, & White, 1997) and are the type of virus that we wish to model.

Stage 2. Identify the information to be obtained from the model

Once an overall understanding of the system has been developed, the question that motivates the model needs to be formulated. The formulation of this question is critically important, since it provides the foundation for designing the model. Asking the question: "How fast will our school become infected when a new macro computer virus appears?" will yield a vastly different model than “Will my computer become infected by the new virus?” In the first question, the model examines the average behavior of the computers, whereas for the second question the model examines the behavior of individual computers. Like most design processes, modeling is a balancing act. Improving the quality of a model (e.g., increasing accuracy or adding functionality) must be balanced against cost (e.g., time or money). Formulating the question appropriately provides the basis for the balancing decisions. In demonstrating this approach to model development, we will answer the first question.

Stage 3. Research and gather data

Most new models are based on existing knowledge/models and modified and refined to fit the problem at hand. In this stage of model development, the modeler develops an understanding of the process of interest and of the existing models. The viruses under consideration have three main aspects, the payload, the dormancy period, and the infection component (Thimbleby, Anderson, & Cairns, 1999). The payload is the set of commands that, when executed, do something undesirable. The dormancy period is the time lapse between infection and manifestation, where the infection may lay hidden or concealed before manifesting itself. This delay makes the program more difficult to detect by distancing the payload’s actions from the time of infection. The third aspect, the infection component, is the means by which the virus will propagate itself and infect other systems.

This model used herein will draw from similarities between computer and biological viruses. The analogy between biological systems and computers has existed since the inception of the computer age. The computer terms ‘bugs’, ‘environment’, ‘worms’, and ‘viruses’ have strong biological connotations and parallels. This is not without reason, as the processes observed in biological systems can represent the processes and mechanisms at work in the artificial environment of computer systems (Kephart, Chess, & White, 1993). The approach finds its promise in that computer and biological viruses exhibit similar behavior (Thimbleby, Anderson, & Cairns, 1999). Both insert themselves into a host, where they produce an undesirable effect. Both use the resources of the host to replicate their genetic or program code and spread themselves to new hosts, thereby spreading the infection. Finally, both the biological organisms and the computers can be immunized against viral infection to the degree that the virus strains can be identified and effectively targeted.

Nevertheless, it is important to be aware of the assumptions of the analogy, since they impact the model’s development. The first assumption is that homogeneous, symmetric interactions take place (Kephart & White, 1991). In biological systems, there is a certain degree of random physical contact associated with the spread of disease. In contrast, in the computer world, physical proximity bears no relevance. In computer communication, interactions are more likely to occur within organizational groups than geographical groups. In both cases, though, the rates of transmission are linked to behavioral patterns.

In the computer environment, there are computers that distribute or pass information that other computers download and install and there are servers that send out mass mailings and do not necessarily receive information in return. Similarly, users vary in the degree to which they send and receive files. It should also be noted that there are biological viruses that do not have an equal chance of being transmitted by every host (Schneeberger et al., 2004) and this is likely to be the case for the spread of computer viruses over the entire Internet (Chang & Young, 2005).

Stage 4. Brainstorm/generate model structures

In creating and visualizing the system, a graphical model is structured to match the structure of the system being modeled. System matching approaches provide strong benefits in the classroom, since they allow students to structure their models using personal knowledge. The next stage is identifying the subjects of the model and describing their linkages. In the classroom, exploration of potential structure starts with an inquiry of how the subject of the model can be divided. Each of these divisions or categories will become one of the state variables in this model example. A box will be used to denote each state variable, either the school's computers or the computer viruses in this example. Students are then asked to identify the pathways where movement can occur between those categories. The paths are indicated by arrows, with arrowhead(s) indicating the directions of the flow. Flows may be either unidirectional or bidirectional.

As shown in Figure 1, there is an array of possible structures for developing the model, depending on how the system is viewed. In diagram (A), the computers are viewed as a group and have been divided based on their infectious state. In this case, computers change status and flow between the boxes representing the various states. This model is a variant of the SIP (susceptible, infected, protected) model used in human epidemiology (Hannon & Ruth, 1997). In diagram (B), the computers have been divided based on the type of users to allow compensation for differences in user behavior. In diagram (C), the computers are arranged based on the network's topology. In these cases (B and C), the model tracks the movement of the viruses between the computers.

Stage 5. Develop and refine model structures

This stage of designing a model is one of the most difficult to teach, in part because students rarely experience multiple valid choices in their classroom experiences. Unfortunately, in engineering practice and in model development, the luxury of a single solution is seldom available. There is no single "right" model. There are only valid choices.

There are a number of factors that can influence the inclusion or elimination of a model from the overall pool of valid structures. Often, the final, optimal choice is a hybrid of the structures in the initial pool. As with physical design, model development is an iterative process, with decisions to add or remove features of the model occurring continuously. Some methods that are useful in guiding the decisions are:

1. Occam's Razor - '*entia non sunt multiplicanda*' (entities are not to be multiplied without necessity) ("OED Online", 2004). Using this technique, the simplest model that exhibits the desired behavior is the preferred model. This approach has several justifications. It reduces the amount of data required, the number of assumptions, and opportunities for human or computer error.
2. Identification of available information – The data used to build a model or add functionality need to be available and of high quality for the model to be valid. If the information is not available, the model will need to be modified, the missing data acquired, or an estimate of the missing values obtained. All models have limits in their use and these limits are often defined by the data.
3. Matching the model to the question – A model that does not answer the question at hand, whether it is accurate or filled with errors, is useless. Many modeling errors are the result of ill-posed questions or specifications. In addition, calibrating or adjusting the model parameters to meet reality and validation, or checking the results against reality, are critical parts of the modeling process (Haefner, 1996).
4. Matching the model to the available resources – Time and money are two of the biggest constraints in model building. They often amount to the same thing. In the classroom, time is at a premium and teachers need to balance the time constraints of the course with the levels of refinement of the model. Historically, the resolution and complexity of a model was severely limited by the speed of the available computers, their memory, or the software on which they ran. Fortunately, not only has the software developed and matured, but also the speed of student's computers is more than adequate for most models.
5. Comparing the model's sophistication and accuracy to that required by the results – Engineering models are often used as the basis for decisions and designs. The time that is spent acquiring quality data and validating a model is dependent on the benefits of getting a right answer and the penalties for failing to get a right answer. Often these benefits/penalties are measured in hundreds of thousands of dollars, jobs, or human lives.

Using one or more of the methods described above, the model's structure and variables are finalized. While all of the structures in Figure 1 can be made to work, implementing model structures B and C will require that each of their blocks be broken down into a structure similar to that found in structure A. Though B and C are more complex, the additional information that they generate is not required. Therefore A is the most appropriate structure.

In structure A, the overall population of items (the computers) is categorized as having one of three states (Hoppensteadt & Perkin, 2002), each represented by a box in Figure 1A. They are:

1. *Susceptible Computers (S)* – These computers do not currently have the virus *and* are capable of contracting the virus.
2. *Infected Computers (I)* – These computers are currently infected with the virus *and* are capable of transmitting the virus to others.
3. *Protected Computers (P)* – These computers are those who do not fall into either of the above populations. Typically, they fall into one or more of the following categories: naturally immune to the virus (running different software), immune to the virus due to immunization (have current antivirus software), and currently infected but not contagious (not connected to the network).

These three variables have values assigned indicating "number of computers." Mathematically, each state represents a first order differential equation. Using a graphical programming language for implementation, transfers the challenges of writing the equations and their solution to the software, allowing students to concentrate on the structure of the problem and the solution of models that are beyond their mathematical skills.

Computers do not necessarily stay in any one state. If they did, this model would be uninteresting both practically and theoretically. Instead, they are moved from one state to another via the pathways. In this example, four pathways for aggregated changes of the computers' state will be allowed. By defining the values and constants involved, this model mimics the behavior of the defined virus through a population. The four pathways are:

1. *Susceptible computers become infected computers* ($F_{S\text{-}I}$) – a virus infects a computer,
2. *Infected computers become protected computers* ($F_{I\text{-}P}$) – the virus is removed from the computer and the antivirus software is updated,
3. *Infected computers become susceptible computers* ($F_{I\text{-}S}$) – the virus is removed from the computer, but the antivirus software is not updated, and
4. *Susceptible computers become protected computers* ($F_{S\text{-}P}$) – current antivirus software is installed on a non-infected computer.

All of these flows are expressed in "computers per day." Definition of these pathways completes the definition of the model's structure, and the specific information describing our situation needs to be added.

Stage 6. Implement the model

Next, the model must be converted into a computer program for simulation. In Stella, this conversion is relatively simple. The conversion of the structure is shown in Figure 2A. The next stage in the implementation of the model is identifying the causes and magnitudes of the flow rates. The definitions of the four pathways for flow within this model are shown in what follows.

Infection of a computer by a computer virus. If every host has an equal chance of interacting with any other host, the rate of interaction is proportional to the product of the number of susceptible and infected computers (Anderson &

May, 1991). More infected computers and more available susceptible computers result in faster spread of the computer virus. Algebraically, this is:

$$F_{S\text{-}I} = ß \bullet S \bullet I$$

Where: ß = Infectious contact rate including virus dormancy [1 / (Computers • Day)]

The contact rate ß is the average number of events of possible transmission per unit of time (Frauenthal, 1980).

Virus removal with installation of antivirus software. The second flow is the flow of individuals from the infected population to the protected. It occurs when a computer has the virus removed and the antivirus software updated. This flow is proportional to the total infected population and the recovery rate following infection divided by the total time from infection to recovery. The recovery rate is the proportion of the infected to be cured and successfully converted to the protected status. The total time is expressed as a latency, ρ, which is the inverse of the time from infection to discovery and the time between discovery and cure, yielding (Anderson & May, 1991):

$$F_{I\text{-}P} = I \bullet \gamma \bullet \rho$$

Where: γ = Recovery rate [non-dimensional]
ρ = Response latency [1 / Day]

Virus removal without installation of antivirus software. This flow represents a situation where an infected computer is subjected to a one-time cleaning process without an update to the antivirus software. Thus, the computers in this state are still vulnerable to future virus attack. This flow is proportional to the total infected population and the probability of cleaning the infection without complete immunization from the time of infection to recovery.

$$F_{I\text{-}S} = I \bullet \delta \bullet (1 - (\gamma \bullet \rho))$$

Where: δ = Virus protection availability [non-dimensional]

Installation of antivirus software on an uninfected computer. This fourth flow is an extension of the basic SIP model, and represents the possibility that individuals will learn about a new virus afflicting others and become immunized in anticipation of possible infection, protecting him/her from the virus without having gone through the infected stage. This is particularly appropriate for an academic setting where a single agency administers control over computer laboratories. It assumes that the information upon which action will be taken is proportional to the susceptible population who stand at risk multiplied by the number of individuals who have learned of the virus.

$$F_{S\text{-}P} = \alpha \bullet (I + P) \bullet S$$

Where: α = Immunization/communication rate [1 / Computers • Day]

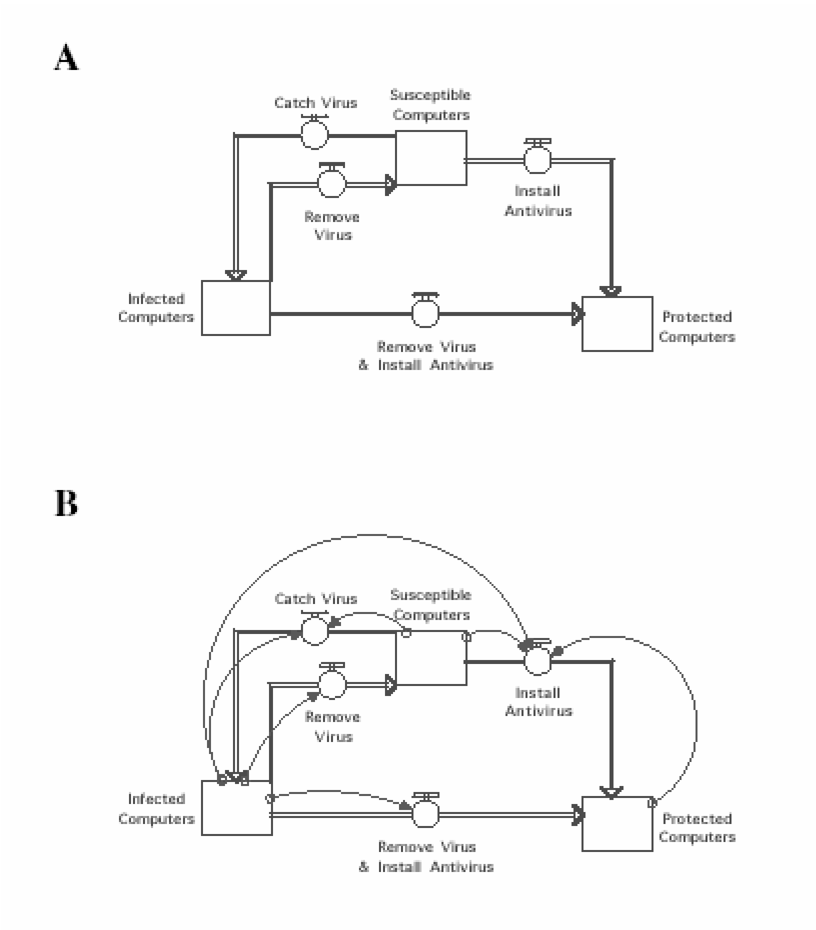

Figure 2. A depiction of the SIP model relationships as implemented in Stella in 2A. The double headed arrow between the susceptible and infected computers in Figure 1A has been replaced by two flow paths because the rate of virus infection and virus removal are different. The SIP model fully implemented in Stella is shown in 2B.

The immunization/communication rate is based on the probability that information concerning the virus will be conveyed to the susceptible population and that the information will be acted upon.

The coupled differential equations describing this model are shown in Table 3. These equations are known as the state equations for the model. In aggregate, they describe the changes to the state variables.

Table 3
The set of coupled differential equations describing the computer virus model. The upper equation for each state variable is written in terms of the pathways and the lower equation includes the equation for each pathway. By using the design paradigm and the graphical modeling software, the modeler has been able to create a complex model without requiring the mathematical or programming background otherwise required.

State Variable	Assembled Differential Equations
Susceptible Computers	$\frac{dS}{dt} = -F_{S-I} - F_{S-P} + F_{I-S}$ or $\frac{dS}{dt} = -\beta SI - \alpha(I+P)S + I\delta(1-\gamma\rho)$
Infected Computers	$\frac{dI}{dt} = F_{S-I} - F_{I-P} - F_{I-S}$ or $\frac{dI}{dt} = \beta SI - I\gamma\rho - I\delta(1-\gamma\rho)$
Protected Computers	$\frac{dP}{dt} = F_{I-P} + F_{S-P}$ or $\frac{dP}{dt} = I\gamma\rho + \alpha(I+P)S$

Stage 7. Specify and simulate

The final step before actually running any model is entering the specific values describing the situation of interest. The example model requires three initial conditions, shown in Table 4, and five rate coefficients specifying the flows between the states, shown in Table 5. The initial conditions assume that the computers are largely unprotected against the virus, as would occur with a new virus. The rate constants describe a rapidly spreading virus and a very rapid response by the generator of the antivirus software and the computer technicians at the school.

Table 4
The initial distribution of the computers between the various state variables.

State Variable	Symbol	Number of Computers
Susceptible	S	195
Infected	I	2
Protected	P	3
Total Number of Computers		200

Table 5
The values of the rate coefficients used in the simulation. The values have been arbitrarily chosen.

Coefficient	Symbol	Value
Infectious contact rate	β	0.15
Recovery rate	γ	0.10
Response latency	ρ	0.33
Virus protection availability	δ	0.25
Immunization rate	α	0.05

The assembled model after the implementation of the equations and the inclusion of the initial conditions and rate constants is shown in Figure 2B. In addition, the results of this simulation are shown in Figure 3.

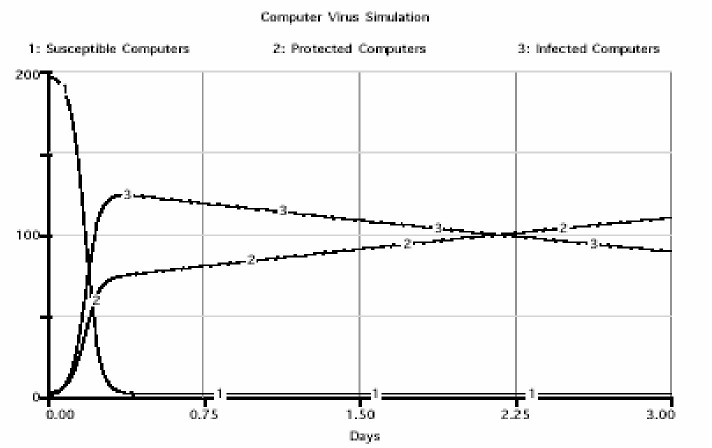

Figure 3. The results of the simulation produced by Stella. The simulation shows a rapid decline in the number of susceptible computers with concomitant rises in the number of protected and infected computers. Later, the number of infected computers decreases as their viruses are removed and protective software is installed. The simulation was performed using a numerical integration with a step size of 0.01. The integration was performed using a 4th-order Runga-Kutta.

Stage 8. Interpret and communicate

Once a model is complete, it will be used, often by those who did not design it. Full documentation is an essential component of any design process. Typically, this documentation will include:

1. Identification of all components, assumptions, and limitations of the model,
2. Documentation of the software under which the model operates, and
3. Printouts of the model and typical results.

It is worth noting that models are also intellectual property. Complete documentation should include the filing of documents to protect that property. This protection is an important business issue. Consulting firms sell the results of their simulations and, as noted earlier, many computer games contain significant computer modeling components. To put it in perspective, one major computer games company, Electronic Arts, had a net revenue of 1.3 billion dollars for the final quarter of 2005 (Tamaki, 2006).

Stage 10. Perform post-implementation review

In addition, the modeler needs to understand that the model that has been created will need to be updated or modified. In our example, a new virus may emerge with different properties. New computers may be added to the school. The school district may want to understand the impact of the virus on all of the schools under its control. In the case of computer models of electronics, new parts will become available. In the case of computer games, a new version of the game will need to be created.

An important component of any design process is the evaluation review that should occur after the model has been completed. There are three broad categories that need to be considered, including

1. What did we do right?
2. What did we do wrong?
3. How can we improve our process?

The modeler will generally be asked to create new models in the future and modify the present model. Understanding the successes and failures of the process used to create the model will result in a smoother, more efficient design process the next time it is performed. A useful analogy is that of the toolbox. Each model adds techniques to the engineer's or designer's toolbox. The post-implementation review helps the modeler to understand the strengths and limitations of their tools.

Conclusions and Implications

The ten-stage modeling paradigm represents a method for the development of engineering models. It adapts a design paradigm used in technology education for the creation of these models. Furthermore, instead of requiring the development of computer code in Basic, FORTRAN, or other manual analytical solution for simultaneous differential equations, this approach graphically develops the structure of the model and implements the model in graphical modeling software. By defining state variables and the flows into and out of the variables using algebraic equations, complex engineering models can be developed and solved in high school classrooms.

The introduction of design-based methodology for graphical model development has a number of implications for technology education. First, it builds on the historical strengths of technology education such as hands-on experiences, visualization, and design and uses those approaches to bring relevance to students' mathematics and science skills. Further, this is achieved by meeting the goals of the *Standards for Technological Literacy* (ITEA & TAAP, 2000) through application of the content of the *National Science Education Standards* (National Research Council [U.S.], 1996) and the *Principles and Standards for School Mathematics*(National Council of Teachers of Mathematics, 1989). Second, it teaches the transferability of the design process to other disciplines by following paradigms that are familiar to both students and the teachers of technology education. This familiarity reinforces the design paradigms in the students' minds, while extending their abilities. Finally, by using software to create and solve the mathematical models that are constructed, the approach is less dependent on the abilities of the students to perform mathematical manipulations. In fact, it is relatively easy to create and solve mathematical models that are analytically insoluble even for many practicing engineers.

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Why Should I Stay? Factors Influencing Technology Education Teachers to Stay in Teaching Positions

Luke J. Steinke and Alvin R. Putnam

Introduction

Technology education is facing no more critical issue than that of its current teacher shortage (Wicklein, 2005). Research conducted by Meade and Dugger (2004), Ndahi and Ritz (2003), Newberry (2001), Ritz (1999), and Weston (1997) have all indicated that technology education has been and will continue experiencing a significant teacher shortage unless action is taken to reverse this problem. Wicklein (2005) indicated that in order to address the issue of the teacher shortage, efforts need to be aimed at recruiting, preparing, and retaining technology education teachers at all levels. This study sought to identify effective retention techniques by determining the factors that influence technology education teachers to stay in teaching positions. The study utilized the survey technique to gather perceptions from technology education teachers and administrators who were elected officials in state technology education associations.

Background to the Study

The National Center for Education Statistics (NCES, 1998) stated that the demand for new teachers comes about primarily because teachers choose to move from or leave the teaching profession at a much higher rate than do those people in other occupations. Studies have indicated that as many as 14 percent of teachers decide to leave the teaching profession after one year and almost half (46%) are gone by the end of their fifth year of teaching (Darling-Hammond, 1999; Fulton, 2003; Ingersoll, 2001; NCES, 1998; National Commission on Teaching and America's Future (NCTAF), 1996; Whiterner, Gruber, Rohr, & Fondelier, 1998).

Teachers leave the teaching profession for many different reasons. Researchers have found that among other reasons, low salaries, lack of career

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advancement, lack of professional development, lack of administrative support, student and peer issues, and other school-environment related factors have been identified to influence teachers to leave the profession (Darling-Hammond, 2003; Marlow, Inman, & Betancourt-Smith, 1996; McCreight, 2000; Marso & Pigge, 1997; Ladwig, 1994). In studies of technology education teacher attrition, Wright (1991) and Wright and Custer (1998) found similar results. In the 1991 study by Wright, the top four factors that affected technology education teacher attrition related mostly to administrative and economic factors and included: lack of support by the administration, low salary or lack of benefits, budget restrictions, and lack of academic freedom or lack of a choice in teaching. The study also identified personal and professional reasons for technology education teacher attrition such as a low status among colleagues outside technology education and lack of understanding of technology education as a subject.

A 1998 study by Wright and Custer also identified the most frustrating aspects of teaching for technology education teachers. The findings of their study also indicated administrative factors as the most frustrating aspect of teaching technology education, which was a lack of funding for equipment, supplies, and facilities. A lack of understanding and support for technology education by administrators and counselors, as well as a decline in the personal characteristics and attitudes of students in technology education were the other factors most highly rated by technology education teachers.

While all areas of education feel the effects of teacher attrition, mathematics, natural sciences, and technology education are especially vulnerable to teacher attrition because they offer professionals the opportunity to make much higher wages working in non-teaching careers (National Association of State Boards of Education, 1998). Since these areas of education are already at a disadvantage when it comes to teacher attrition, a focus must be placed on effectively retaining the teachers who are currently employed in these areas. Many researchers have found that a focus on retaining teachers may actually be more effective in addressing a teacher shortage than a recruitment focus (Merrow, 1999; Ingersoll, 2001).

Several different programs have been developed in order to retain teachers and other educational staff. Two programs developed for retention are staff orientation, and induction and mentoring programs. The purpose of a staff orientation program is to provide new teachers with an overview of the school and curricular activities (Stansbury & Zimmerman, 2000) and such efforts have been found to increase retention rates by nearly 35 percent (Lemke, 1995). Additionally, induction and mentoring programs which provide first year teachers with the opportunity to share experiences and collaborate have been found to double the chances that the teacher will stay in his or her profession (Brown, 2003).

Other suggested strategies for retaining teachers include: effective school leadership, signing and retention bonuses, effective staff selection and development, effective relationships with the community, higher teacher salaries, flexible teacher schedules, shared decision making, career ladders, merit pay, performance pay, and loan reduction or forgiveness (Ingersoll, 2001; Kuenzi, 2004; Minarik, Thornton, & Perreault, 2003; NCES, 2003; Odden & Kelley, 2002).

While many areas of education are experiencing teacher shortages, several studies have focused on reasons teachers leave the teaching profession. Few studies however have identified factors that influence teachers to stay in teaching positions. Studies conducted by Puget Sound Educational School District (PSESD) (2003) and Hare and Heap (2001) have examined factors influencing teacher retention within Washington State and Midwestern states respectively. Marquez (2002) conducted a study that examined the factors that influenced the retention of bilingual education teachers. Additionally, Barrows and Wesson (2003), Lee, Clery, and Presley (2001), and Weiss (1999) identified job satisfaction factors that may impact teacher retention. However, if the teacher shortage in technology education is to be addressed, specific studies addressing the factors that influence the technology education teacher human resource supply are needed.

Hanushek, Kain, and Rivikin (2001) stated that without a full understanding of the factors influencing the teacher supply, effective policies and strategies to address the teacher shortage will not be developed. This study sought to expand the knowledge regarding the technology education teacher supply by focusing on the factors that influence the retention of technology education teachers. The purpose of the study was to determine the factors most influential in whether a technology education teacher stays in a teaching position. Based on the findings of this study, effective retention policies can be developed for technology education.

Methodology

The design of this study examined factors that influence technology education teachers to stay in teaching positions. The study specifically utilized the survey method to answer the research questions of the study. The general purpose of survey research was to generalize from a sample population so that inferences can be made about the perceptions of the total population (Babbie, 2001). The study sought the perceptions of technology education teachers and administrators who served as elected officials in their respective state technology education associations. This population was defined as described for several reasons. First, a population was needed that involved both technology education teachers and administrators. These individuals were chosen because of their specific knowledge of technology education, and the factors that influence technology education teachers to stay in teaching positions. Second, by the nature of their involvement in a technology education association as an elected officer, they may have a higher commitment to technology education resulting in a higher, more accurate response. Third, state technology education officers are elected to represent all of the technology education teachers and administrators in the state. Therefore the perceptions of those technology education teachers and administrators should be representative of other technology education teachers and administrators in the state. Finally, the identification and contact information for state technology education association officers were available to the researchers on the state association Websites or by contacting each association directly.

After extensive research of the International Technology Education Association Website and state technology education association Websites, 32 states were determined to have technology education associations with a total of 489 elected officers. The 489 elected officers consisted of approximately 401 technology education teachers and 88 technology education administrators. Elected positions in state technology education associations are voluntary positions consisting of presidents, vice presidents, past presidents, president elects, secretaries, treasurers, and other state board positions such as regional/district representatives. This study only surveyed technology education teachers and administrators. Board members who represented universities and community colleges were excluded.

The researchers developed a survey to determine the factors that influence technology education teachers to stay in teaching positions. The initial survey development was guided by three instruments: The Job Satisfaction Survey (Spector, 1985), Recruitment and Retention Issues Survey (PSESD, 2003), and Retaining and Attracting High Quality Teachers Survey (Hare & Heap, 2001). These surveys served as a guide in the development of the broad categories and general factors influencing teacher retention. Factors specific to technology education were determined by the researchers through a review of literature.

The content validity of the survey instrument was established by means of a panel with expertise technology education (n = 5). The panel consisted of five technology education professionals from two regional Midwestern universities. They examined the instrument for grammar, clarity, and understanding. Additionally, the survey instrument was pilot tested with technology education teachers (n = 34) and technology education administrators (n = 10) at the Association of Career and Technical Education (ACTE) conference in December of 2005 to determine internal consistency reliabilities of the scales and to assess understandability. A Cronbach Coefficient Alpha test was conducted for the pilot test instruments to determine the internal consistency of the instrument and to establish reliability for the survey instrument. After eliminating two categories from the survey, a reliability index of .969 was determined for the instrument.

The survey consisted of two sections. Section one collected basic demographic and background information to provide a better understanding of the population sample. The second section listed 28 retention factors, which were categorized into pay, promotion, benefits, contingent rewards, operating conditions, nature of work, and communication. Table 1 contains a list of the 28 factors.

Table 1
Factors influencing technology education teachers to stay in teaching positions

	Pay Category
1	The current salary is comparable to that of the national average ($30,000).
2	The technology education teacher is paid above the district average.
3	Raises for technology education teachers are above the district average.
4	The school is providing yearly raises for all teachers.
	Promotion Category
5	There is a career ladder for technology education teachers in the school district.
6	Technology education teachers are promoted based on performance.
7	Technology education teachers can move up the career ladder quickly.
8	Technology education teachers are promoted based on tenure procedures.
	Benefits Category
9	There are resources available for professional development.
10	The school is paying off the teacher's student loan.
11	The school is providing a tuition waiver or reimbursement for continuing education.
12	The teacher is offered a financial reward (retention bonus) for staying a certain number of years.
	Contingent Rewards Category
13	The school is providing successful teachers with non-financial rewards.
14	The school is recognizing successful teachers within the district.
15	The school is financially rewarding teachers for school and program successes.
16	The school is providing increased compensation for quality teaching.
	Operating Conditions Category
17	Technology Resources are upgraded for the classroom and labs.
18	Class sizes are average (20 to 25).
19	The school is providing retraining for faculty and staff.
20	The school has a university partnership to recruit, alternatively certify, and train teachers.
	Nature of Work Category
21	The school is using the Standards for Technological Literacy.
22	The technology education teacher is teaching the grade they prefer to teach.
23	The technology education teacher is teaching the subject they prefer to teach.
24	Technology education is housed under Vocational Education.

Table 1 (continued)
Factors influencing technology education teachers to stay in teaching positions

	Communication Category
25	The teacher participated in a new teacher induction program to orient new teachers to the school.
26	The teacher is participating in a mentoring program in place to help new technology education teachers.
27	There is a collaborative work environment.
28	Teachers are involved in the decision-making process.

The second section asked participants to respond to each factor, and rate each as to its influence on whether a technology education teacher stays in a teaching position. A five-point Likert-type scale was used for each of the items with “1” representing strong disagreement that the factor is influential and “5” representing strongly agreement that the factor is influential.

Data Collection

The data collection process began in January of 2006. The 489 participants selected for the study were each sent a personalized email introducing the project, describing the purpose of the study, providing instructions for completing the survey online, assured confidentiality, and directing them to the site where the instrument could be completed. The researchers attempted to increase the response rate by requesting the assistance of state technology education association presidents, presidents-elect, and executive directors. Each of these individuals was sent personalized emails asking for their assistance in the study and for them to encourage their board members and regional/district representatives to participate. A follow-up mailing was conducted exactly one week after the first and a final follow-up was sent two weeks after the first mailing. Of the initial 489 surveys sent, 95 were returned as undeliverable and 230 of the 394 participants receiving the mailing (58.4%) returned the survey.

Findings

Data collected were analyzed and used to determine the factors influencing technology education teachers to stay in teaching positions. Descriptive statistics were calculated for both demographic information and the factors including means, standard deviations, frequencies, and percentages. Frequencies, means, and standard deviations were used to summarize and describe participant responses to the factors that influence technology education teachers to stay in teaching positions.

An analysis of the demographic data received from the study indicates that participants from all 32 states surveyed responded to the study. As reported in Table 2, the majority of those responding to the study (83.0%) identified themselves as technology education teachers. While only twenty respondents classified themselves as administrator, an additional 7 respondents identified themselves as both teachers and administrators and twelve respondents answered in the *other* category.

Also reported in Table 2, approximately 30.4% of respondents (*n* = 70) worked at the elementary/middle school level and 11.3% (*n* = 26) worked at the state/district level, while the majority of the respondents (*n* = 126) indicated they worked at the high school level. Finally, respondents were more evenly split between locations with 22.6% of respondents in rural areas (*n* = 52), 29.1% located in towns or small cities (*n* = 67), 33.0% in suburban areas (*n* = 76), and 13.5% respondents in urban areas (*n* = 31) (see Table 2).

Table 2
Descriptive information about the respondents

Variable	*n*	%
Position Held		
Teacher	191	83.0
Administrator	20	8.6
Both	7	3.0
Other		
State Supervisor	8	3.4
Program Specialist	1	<.01
State Consultant	1	<.01
Department Head	2	<.01
Area of Work		
Elementary/Middle	70	30.4
High School	126	54.8
State/District Level	26	11.3
Other		
Both or K-12	8	3.4
Location		
Rural	52	22.6
Town or Small City	67	29.1
Suburban	76	33.0
Urban	31	13.5
No Response	4	1.7

Means ranged from 2.61 to 4.11 for all respondents on a Likert-type scale (1 = Strongly Disagree, 2 = Disagree, 3 = Undecided, 4 = Agree, 5 = Strongly Agree). There were a total of 14 factors rated with means of 3.5 and above (agree) on the scale. These data are presented in Table 3. There were 14 factors rated with means below 3.5 (disagree or undecided) on the scale which are presented in Table 4.

Most Influential Factors

Three factors received mean ratings of 4.00 and above and were perceived as most influential. They were the provision of yearly raises for all teachers (Factor 4), the school had resources available for professional development (Factor 9), and the school had a collaborative work environment (Factor 27).

Table 3
Summary of the factors influencing a technology education teacher to stay in a teaching position rated above 3.5

				Frequency of Response (Percent)				
Factor	***n***	**Mean**	**SD**	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Factor 1	228	3.560	1.338	24 (10.4)	33 (14.3)	33 (14.3)	68 (29.6)	70 (30.4)
Factor 4	227	4.110	1.071	11 (4.8)	11 (4.8)	19 (8.3)	86 (37.4)	100 (43.5)
Factor 9	227	4.110	0.967	5 (2.2)	13 (5.7)	26 (11.3)	92 (40.0)	91 (39.6)
Factor 14	225	3.680	1.219	21 (9.1)	18 (7.8)	34 (14.8)	91 (39.6)	61 (26.5)
Factor 17	226	3.990	1.095	10 (4.3)	19 (8.3)	19 (8.3)	93 (40.4)	85 (37.0)
Factor 18	226	3.880	1.137	14 (6.1)	17 (7.4)	25 (10.9)	95 (41.3)	75 (32.6)
Factor 19	226	3.630	1.209	19 (8.3)	23 (10.0)	39 (17.0)	87 (37.8)	58 (25.2)
Factor 21	226	3.730	1.181	17 (7.4)	20 (8.7)	33 (14.3)	92 (40.0)	64 (27.8)
Factor 22	226	3.740	1.126	11 (4.8)	27 (11.7)	32 (13.9)	95 (41.3)	61 (26.5)
Factor 23	224	3.990	1.018	7 (3.0)	15 (6.5)	30 (13.0)	94 (40.9)	78 (33.9)
Factor 25	227	3.830	1.220	17 (7.4)	22 (9.6)	23 (10.0)	86 (37.4)	79 (34.3)
Factor 26	224	3.750	1.153	14 (6.1)	20 (8.7)	40 (17.4)	85 (37.0)	65 (28.3)
Factor 27	227	4.100	0.950	5 (2.2)	9 (3.9)	35 (15.2)	88 (38.3)	90 (39.1)
Factor 28	222	3.910	1.114	13 (5.7)	16 (7.0)	22 (9.6)	98 (42.6)	73 (31.7)

As indicated in Table 3, respondents also perceived that having a salary comparable to that of the national average (Factor 1), having the school district recognize successful teachers (Factor 14), providing upgrades for technology resources in classrooms and labs (factor 17), having average class sizes (factor 18), providing retraining for teachers and staff (Factor 19), using the Standards for Technological Literacy (Factor 21), having the technology education teacher teaching the grade he or she prefers to teach (Factor 22), having the teacher teaching the subject they prefer (Factor 23), having teachers who participated in a new teacher induction program to orient new teachers to the school (Factor 25), having teachers who are participating in a mentoring program in place to help new technology education teachers (Factor 26), and involving teachers in the decision making process (Factor 28) were also influential factors in whether a technology education teacher stays in a teaching position.

When comparing the results above to other teacher retention studies, similarities can be found to factors such as pay, operating conditions, and communication. Studies conducted by PSESD (2003), Marquez (2002), and Hare and Heap (2001) indicated similar results for factors such as providing yearly raises for all teachers, providing resources for professional development, average class sizes, and staff development as influential in retaining teachers. This study also found similar results to Wright and Custer (1998) in suggesting that technology resources were influential in technology education teacher retention. Finally, this study supported Brown's (2003) conclusions regarding the positive influence teacher induction and mentoring programs have on teacher retention.

Non-Influential Factors

Along with indicating the factors perceived to be influential in whether a technology education teacher stays in a teaching position, factors perceived to have less or no influence were also identified. This study found 14 factors (see Table 4) that were perceived to have the little to no influence on whether a technology education teacher stays in a teaching position. The 4 factors perceived to have the least influence were providing raises above the district average for technology education teachers (Factor 2), paying off the teacher's student loan (Factor 10), promoting technology education teachers based on performance (Factor 6), and paying technology education teachers above the district average (Factor 3).

The above perceptions of the respondents are of particular interest for two reasons. The first reason has to do with the factors relating to pay. Several of the studies discussed earlier which looked at attrition rates of teachers indicated that pay was a major reason for leaving the teaching profession. The results of this study would indicate that higher pay wouldn't necessarily be an influential factor in determining whether or not a technology education teacher stays in a teaching position. These findings may result from a desire by technology education teachers to not be paid more or receive higher raises than other teacher, but to be treated and paid similar to the other teachers in the district. The second finding that is of interest is the perception that paying off the teacher's student loan is not influential. This is interesting since student loan payoffs are one of the programs most widely used by states and school districts to retain teachers.

Table 4
Summary of the factors influencing a technology education teacher to stay in a teaching position rated below 3.5

				Frequency of Response (Percent)				
Factors	***n***	**Mean**	**SD**	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**
Factor 2	228	2.800	1.512	67 (29.1)	39 (17.0)	42 (18.3)	33 (14.3)	47 (20.4)
Factor 3	228	2.610	1.493	76 (33.0)	44 (19.1)	42 (18.3)	24 (10.4)	42 (18.3)
Factor 5	224	3.020	1.385	43 (18.7)	44 (19.1)	42 (18.3)	56 (24.3)	39 (17.0)
Factor 6	225	2.780	1.400	57 (24.8)	48 (20.9)	39 (17.0)	50 (21.7)	31 (13.5)
Factor 7	226	2.940	1.305	40 (17.4)	45 (19.6)	64 (27.8)	43 (18.7)	34 (14.8)
Factor 8	226	3.230	1.292	33 (14.3)	29 (12.6)	58 (25.2)	66 (28.7)	40 (17.4)
Factor 10	227	2.740	1.588	82 (35.7)	30 (13.0)	26 (11.3)	43 (18.7)	46 (20.0)
Factor 11	226	3.270	1.542	53 (23.0)	22 (9.6)	25 (10.9)	62 (27.0)	64 (27.8)
Factor 12	226	3.040	1.622	67 (29.1)	28 (12.2)	24 (10.4)	44 (19.1)	63 (27.9)
Factor 13	225	3.120	1.385	44 (19.1)	28 (12.2)	53 (23.0)	57 (24.8)	43 (18.7)
Factor 15	223	2.900	1.484	56 (24.3)	45 (19.6)	32 (13.9)	46 (20.0)	44 (19.1)
Factor 16	225	2.910	1.507	61 (26.5)	39 (17.0)	29 (12.6)	52 (22.6)	44 (19.1)
Factor 20	225	3.040	1.346	40 (17.4)	43 (18.7)	44 (19.1)	63 (27.4)	35 (15.2)
Factor 24	226	2.960	1.448	53 (23.0)	38 (16.5)	42 (18.3)	50 (21.7)	43 (18.7)

These results could indicate that the respondents were older and did not currently have student loans or were teachers who did not have student loans to begin with. The results however are somewhat surprising in that this factor was rated as one of the four least influential.

Other factors that were rated as having little to no influence of note include those pertaining to career advancement and career ladders (Factors 5 and 7).

This finding is contrary to some previous studies. For example, Marquez (2002) found career advancement to be effective in retaining bilingual education teachers, and PSESD (2003) found career ladders to have some influence on teacher retention. The other factor of note that was perceived to be less influential was providing a retention bonus (Factor 12). Similar to paying off teacher's student loans, retention bonuses are one of the more widely used programs to retain teachers.

Conclusions and Recommendations

Many of the factors perceived as influential in this study could be used by schools to develop programs or implement policies to retain technology education teachers. For example, much like the findings of Brown (2003), this study indicated that schools could develop induction and mentoring programs to increase the likelihood of retaining technology education teachers. Additionally, this study suggests that policies could be enacted to create a more collaborative work environment with shared decision making, methods could be developed to recognize successful teachers, and schools could adopt the Standards for Technological Literacy to successfully retain technology education teachers.

Of the other factors perceived as influential, several relate to resources available to schools. While these factors may be more difficult to overcome for schools with fewer available resources, the finding of this study would indicate that many could be implemented without a significant financial burden. Low salaries are often stated as reasons that technology education teachers leave the profession (Wright, 1991; Wright & Custer, 1998). However this study indicated that technology education teachers would be more likely to stay in a teaching position if they were paid comparably to the national average while receiving a yearly raise similar to all teachers in the district. Additionally, factors such as providing higher salaries and raises for just technology education teachers were perceived as having less influence. These findings would suggest that technology education teachers are not necessarily looking to make more than the average teachers, but a similar salary with the potential for a salary increase.

Influential factors to retentions are important, but those with little influence are equally so. The programs often used to retain teachers in school districts such as retention bonuses, tuition waivers, and student loan payoffs were all perceived to have little to no influence. This would suggest that schools might better utilize these resources in acquiring materials and equipment for teaching, providing yearly raises, or providing opportunities for professional development.

While technology education continues to experience a teacher shortage, it is especially important to retain as many of the current teachers as possible. These findings could be helpful to school districts and states alike in providing a better understanding of the technology education teacher population and in developing programs and policies that actually avoid our teachers from leaving the profession. While more research is needed in addressing the technology education teacher shortage, we must first retain the teachers we have so that technology education profession is maintained.

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Editorial

The Human Tendency to Be Technical

Ronald Hansen

Our social and technical history, albeit contested, is our culture as human beings. Yet, it (the technical component) goes unclarified and untold in many ways. To find clarification and "understanding," this research revisits the history of technical learning in and out of schools. (Bennett, 1926, 1937). Case study information from a technical-minded school headmaster is also analyzed in order to clarify a human tendency that is central to understanding how technical education is or is not embraced in the schools.

The concept "technical thinking and learning" is used as way to define the aptitude, ingenuity, and penchant for solving practical problems that technical educators employ in their work (Autio and Hansen, 2002). How do technical people feel about their learning, as individual human beings and as teachers? What do they know? The literature, especially the education literature, does not reflect the passion much less the clarification of what it means to "be technical."

One concern of technical or practical educators is captured in the following question. What is technical learning and in what form does it belong in the schools? The literature (Hansen, 2000; Layton, 1993; Pannabecker, 2004) does confirm that the question is not a new one. It was raised and debated vigorously 200 years ago, just as it is today. Yet questions of nature and form persist, making policy analysis almost impossible. The purpose of this analysis is to probe the roots of technical learning and thinking (TLT) and, in the process, pose questions about learning generally. Why is academic learning so dominant in schools and technical learning not? The personal writing of a subject or subjects about critical incidents (Cole, 1991 ; Tripp, 1993) in their lives provides one method of collecting evidence. An historical analysis is another (Kaestle, 1988).

Long before schools as we know them today Greek philosophers like Plato and Aristotle, debated the purposes and types of human learning. From the

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earliest record one can trace the beginning of academic thinking. Plato wrote about the difference between learning as a purely mental activity versus learning through physical, spiritual, and mental activity. His view was that matters of the mind were more important than matters of the body. Aristotle's analysis was more sophisticated. He differentiated between episteme (theory), techne (technique), and phronesis (practical wisdom). To Aristotle there was an equal amount of intellectual virtue in all three areas. Today, modern schools are operated, almost exclusively, on academic or epistemic thinking. School curricula are, especially at the secondary and tertiary levels, tied to the knowledge disciplines developed over the last three centuries in universities. Technical thinking and learning (learning through experience as well as knowledge), by comparison, has tended not to be a valued method, let alone ideology, for learning.

The following quote from a woodworking teacher provides some insight into one person's tendency to learn technically.

> …it must have been when I graduated from secondary school. At age 19 I decided to spend a year at a practical school in a class that worked with building furniture. Through that year I got to know the inside of a real handcraft with its standards and qualities. It was very meaningful and from that time I have had this tendency to look upon all things in life the way a carpenter does, which I think is a very useful perspective; because it is both realistic (the chair has to be stable) and aesthetic (a beautiful chair is lovely to own), it responds to all sides of the personality in a way that theoretical subjects often lose.
>
> So when I treat my wife in a carpenter's way or make my lyrics (pianist) the same way or if I run this school according to carpentry standards I think the results often become successful. Besides, my dream is, when I am to retire as an old man, I want to be living as a happy carpenter. In fact this thought helps me going good through my days as a headmaster.
>
> *Peter (pseudonym) is a technical teacher and headmaster, 2003*

Peter's TLT tendency is no different than what children experience at the beach. They attempt to build castles and other imaginative things out of water and sand. Is this not being technical? The journal entry from Peter, a fifty year old, is revealing. When he writes "I tend to look upon things in life the way a carpenter does" he is describing his preference for technical thinking and learning. The engineers and technicians who completed the twenty-two mile tunnel under the ocean to join the two nations of England and France were also being technical. The instinct being displayed by both children and adults is the same instinct. It is an inherent biological or genetic given that we attempt to modify the natural environment around us to improve, or experiment with improving, life's comforts and nature's challenges (Burke, J. & Ornstein, R., 1995; White, 1962). When someone asks a non-technician, "are you a technician?" chances are most people would answer no. Not everyone earns a living doing technical work even though the instincts and tendencies are there. There is a little technician in each and every one of us according to Ortega y

Gasset (1962). Gasset, in his chapter "Man the Technician," defines technology as the extra natural program that is man (sic) himself. To behave technically is so common that we take it for granted. It becomes invisible.

The finest written material on technical accomplishment is done by historians. Durant (1977), for example, in his autobiography, is careful to point out how inventions like the printing press and the grinding of glass were critical to human and cultural development over time. White (1962) and Burke & Ornstein (1995) have documented how civilization as we know it today is an evolutionary story traceable consistently to the technical instincts of men and women. Bennett in the early decades of the nineteen hundreds wrote a comprehensive history of technical learning. The following analysis aims to: define TLT; find a way to express a technical "way of knowing" that words alone cannot convey; reveal how school learning displaces experiential learning.

The History of Technical Learning and Thinking

The earliest forms of "technical being" date back to 700 BC. The defining achievement of this early period was the controlling of fire. At this point humankind was able to cook food, melt metals, and shape tools. Eventually humans became miners, smiths, carpenters, masons, weavers, and so on. Systematic learning, if there was such a thing during this stage, is not well documented. It was a natural and instinctual process, you might say. The first evidence of organized learning came from groups who valued a trade, skill, or craft. Ancient Jews, for example, sent their children to school for religious studies in the morning and skill development in the afternoon. Failure to give a Jewish boy an honest means of livelihood (manual trade) was to exclude him from becoming a useful member of the community (Bennett, 1926). Furthermore, the Jewish people felt labor held religious significance. It was regarded as a man's (sic) duty.

At no point in the pre-renaissance period is there what could be called a system of instruction. Sons and daughters learned from their fathers and mothers. Their goals were always survival and betterment for the family members and eventually for larger communities of people. Even if a son was taught by someone other than his father or mother the relationship was a paternal one, master and apprentice. During the Homeric age (700 to 300 BC) Greek handicraft people respected mechanical aptitude. Later, however, mechanical arts lost their status. Much like the status of technical learning in schools today, experience (compared to the neat and tidy academic-based curriculum organizers) is a cumbersome, undervalued, and poorly understood phenomena/framework for learning. The beginnings of a stigma emerged. Manual arts were thought to be for the peasant class and not fit subject matter for upper class youth. In 300 BC upper class boys were taught drawing. The lower classes continued to apprentice under a master as in earlier times. Interestingly, the orators, lawyers, and physicians of the time employed the apprenticeship method in their training.

Christian monks, much like the Jews, elevated manual labor. Labor was required of everyone – weavers, carpenters, curriers, and tailors. Similarly, the Benedictines (450 –600) made manual labor a cardinal principle. Their thought was that labor banished indolence (the enemy of the soul). For every time they celebrated the praises of God they devoted one hour to labor. The religious zeal and missionary enthusiasm of the Benedictines carried them from Italy, north of the Alps, into Germany. Germany became filled with monasteries each of which became a center of civilization. Many of the church structures from 900 to 1200 are the work of Benedictines. Bookmaking and building followed with the development of the printing press in 1450. "Through the promotion of agriculture, the handicrafts, and art, along with religious instruction for all, and book learning for a selected few, the Benedictines became the civilizers of barbarians and examples of enterprise, thrift, and Christian culture" (Bennett, p. 20). The sole educational institutions of this period (900 – 1500) were monasteries. Their subject matter was religious writings. "Outside of the monasteries, participation in skilled labor was the principal means of education, though not the kind of education which was recognized as such by schools" (p. 21). As trades and crafts developed i.e., became more differentiated and specialized, apprenticeship included a large body of information, tools, and techniques. The master was to teach the recipes, rules, applications of science, mathematics, and art of the craft. The method was imitative and most instruction was outside of school walls.

A new conception of the process of learning began to emerge in the 1400's; the same spirit that led to discovery of new methods for the schools. According to Bennett, this period spawned two new fundamental ideas upon which modern instruction in the manual arts has been built (p. 30). The first is that the senses are the basis of thought, and consequently, of knowledge. The second is learning by doing. The idea that children could learn by working through a process and making something by themselves, with tools, was seen as rational thinking. The expansion of public schools and the placing of handicrafts in schools followed, both predicated on the belief that learning was a physical as well as cerebral act.

British thinkers began to contribute to the technical learning story in the 1600's. It was Francis Bacon (1561 – 1626) who first articulated learning based on nature and the arts of daily life. Comenius followed (1592 – 1670) by advocating learning that starts with the senses, then memory, the intellect, and finally the critical faculty. "The child perceives through the senses; every thing in the intellect must come through the senses" (p. 36, cited in Bennett). In 1663 Moxon published a volume entitled "Mechanik Exercises or the Doctrine of Handy Works." The subjects ranged from smithing to joinery and made extensive use of illustrations. Locke (1642 – 1727) became the main spokesperson for the idea that education should "fit a boy for practical life" (Bennett, p. 61). Rousseau (1712 – 1778) took Locke's ideas a step further. He believed agriculture was the most respectable of all arts and professions. Next to this came smithing and then carpentry. Bennett quotes Rousseau: "The great secret of education is, to make the exercise of the body and mind serve as relaxation to each other" (p. 80, cited in Bennett). Ultimately, technical learning found its way into the school curriculum across Europe alongside but different from the classic academic subjects of mathematics, science, language, history, and religion.

It was in the early 1800's that developed countries of the world began to search more deliberately for technical knowledge and wisdom. The industrial revolution was well underway and advancements of all kinds were surfacing, e.g. the harnessing of steam for power, the development of water and sewer systems for towns, the controlling and distribution of power for factories, etc. From these developments and the migration habits of people came the need for people to be technical and productive in new ways. They needed to learn from one another more now that ever before. Practical knowledge of the local artisan, farmer, or smith, needed to be shared to solve larger and universal problems. Technicians were now needed in greater numbers; someone who could apply individual ingenuity to large-scale needs and problems, e.g., larger boats for transporting goods on water, engines to power-boats, trains, and eventually cars. Societies around the western world were moving ahead into a mechanical era, not unlike the electronic era today.

The Devaluing of Technical Learning and Thinking

It is doubtful the devaluing of technical thinking and learning can be attributed directly to the industrial revolution. Many philosophers since this time have debated the essence of how people learn and what aspects of that learning are significant. Dewey recognized and tried to explain how learning was first and foremost an experiential process, not an academic or intellectual one. However, his views along with those of others, have had very little impact on school leaders and programs. Part of the problem Dewey and others confronted was an absence of an answer to an important question. How do people learn? Similarly, the historical roots of technical learning are not documented or, when they are documented, they are not framed very well. Technical thinking and learning pre-dates academic learning but is not written about or articulated in books or archival materials. These important undocumented roots are traceable to the early conquerors, the Romans and the Vikings, of earlier times and to indigenous cultures, e.g., aboriginal peoples, today. They (the roots) are found in museums, in non-print archives, and in oral stories. Artifacts from Viking and Roman archeological sites, for example, testify to the creativity and functionality of tools, jewelry, social organization, and building structures developed in early times. Viking boats have been discovered dating to the early ninth century. They used a building process and a design that indicates a timeless intelligence and ingenuity.

This kind of ingenuity reflects years of trial and error, years of technical learning and thinking. It was passed on orally and in the form of artifacts from one generation to another. Wooden and metal templates were made, modified, and passed down. In today's society evidence of TLT is obscured. It can be found in the oral traditions and artifacts of indigenous groups. Unfortunately these sources of study and learning are discounted as being unimportant. The trial and error learning process tends to get overlooked in the rush for efficiency and cost effectiveness. Today's technological inventions and advancement, by comparison, are useful but not always as dependable over time. What remains constant is the invention process. A need or perceived need is followed by rudimentary designs and prototypes, to finished functional products. While the process of learning is still pragmatic and experiential at the core, the way we disseminate information about it takes on an academic appearance. Knowledge is separated from the historical experience that created it, leaving the essence of TLT concealed.

Today we use the term "problem solving" to teach young people about the historical and universal process. What is the problem for which a stable and dependable boat is the solution? The fact that the two kinds of thinking and learning (academic versus technical) are very different, may be one of the explanations for why TLT has not been articulated clearly and why it has not found a home in formal schooling practices. There is a resulting conundrum. The notion of constructing knowledge and creating academic subjects for its dissemination is itself an anomaly. McLaren writes:

> Critical education theorists view knowledge (school subject knowledge) as historically and socially rooted and interest bound. Knowledge acquired in school – or anywhere, for that matter – is never neutral or objective but is ordered and structured in particular ways; its emphases and exclusions partake of a silent logic. Knowledge is a social construction (p. 173).

The fact that school knowledge and its dissemination is contrived or constructed and that it has limitations comes as quite a revelation to many education leaders today! Sheridan states, "schooling contributes to a priority of legitimacy of literacy, and this denies the legitimacy of experience, which is necessary for learning" (p. 23). School teachers, moreover, are not taught about this dichotomy, this contradiction. A significant dilemma in schools awaits exposure. Ironically, this "missing understanding" is spoken about informally in workplaces and around the kitchen table all the time by families and people who trust their experience and life's work ahead of what they learned or did not learn in schools.

There is a classic question that grows from this dilemma. Can schooling which depends so heavily on a single and narrow model of learning be condoned? Dewey writes: "Connect schooling to everyday life and the curriculum will necessarily be relevant." Layton underscores the same point when he states that schools decontextualize knowledge (p. 15).

If "being technical" were better understood and articulated in schools would our attitudes towards and understanding of those around us who design, build, and use technology be more complete? The limited number of ways to convey to others what it means to be technical poses a challenge to technical teachers. Given the limited historical documentation of what it means to be technical, to feel what a technician feels, to explain how this history augments understanding and human existence, the prospects are not good. The very telling of the TLT story is problematic. Can words ever convey what it means to be technical as a human being? Can the understanding and political will ever be sufficient to enable a TLT ethic to prevail? Technical achievements are of a physical and experiential nature. These achievements and the learning process associated with them do not, over time, flourish in schools. Being technical isn't something that is easily expressed or impressed.

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Miscellany

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