A Conceptual Framework of Ideas and Issues in Technology Education

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I. Introduction

Ideology and content combine to create curriculum for the schools as teachers and the educational community collaborate to plan for teaching. Over years of efforts in the schools to teach about technology many of the ideas which fuel the curriculum have been discussed, presented, and implemented in schools. This conceptual framework discusses our past and our present concerns regarding technology education with the hope that the future will be created.

There are six substantial chapters in this conceptual framework, some representing the past and some representing the present. Inspired by the *Standards for Technological Literacy* (ITEA, 2000) the conceptual framework looks at where we have been both by action and ideology, where we are today as a field rapidly adopting inquiry and engineering as practice, and to the future of how we can fit into the curriculum and the purpose of education and schooling.

The chapters cover the history of what has been done in technology education, the ideology that supported historical practices and continues to influence practice today, inquiry and how inquiry leads to further engagement with science educators, design and what we can learn from engineers, the role of creativity in technology education, and the role of language in the teaching of technology.

Based in a two part history, both of events and ideology, of technology education, this conceptual framework can serve as background for the discussion of what technology education ought to be and what technology educators ought to be doing.

In addition, the standards are focused on design as a major idea and method for technology education, to be woven throughout the contexts of technological knowledge. The new emphasis on design is also accompanied by a move towards integration with other subjects such as science and the role of engineering with regard to technology education curriculum. This conceptual framework takes up the role of inquiry, design, and engineering in technology education.

Finally, the framework looks to theory in order to frame a discussion of how technology education can serve as a fundamental subject in the schools' curriculum, serving as a means of learning language.

However, the framework does not provide the answers to these questions, rather, it provides a great deal of information for the discussion of the issues that face technology educators. It was written from the perspective that teachers, teacher educators, and students of technology education can use this as a reference and frame for discussions of the past, present, and future of technology education.

II. Where We Have Been

As a subject matter that represents an evolving body of knowledge, technology, there has been an historical effort amongst the members of this field to continue to define and redefine the content that would be appropriate to teach in schools. From the outset of early practice in the field, the selection and definition of content, as well as, the name of the field has been problematic. These problems relate directly to the fact that over time, terms and knowledge associated with technology have continued to evolve and change as people learn and invent more ways of doing and ways of communicating about doing. Moreover, those who do technology encompass all humans and a good number of other species, and those who study, create, and invent technologies involve a number of different fields of study including engineering, science, medicine, and information technologies, to only mention a few. It is no wonder that a small field such as technology teacher education with relatively few practitioners can have difficulty getting a grasp on the content that needs to be selected, organized, and taught to students in schools and in teacher education programs. Attempting to maintain a contemporary selection and definition of technology education content has been and will continue to be a challenge due to the nature and intent of the subject matter.

At present, technology educators in the United States have adopted a set of standards for technology education. Those standards, by title, *Standards for Technological Literacy: Content for the Study of Technology*, purport to offer a "beginning" to the definition of content for technology education (International Technology Education Association, 2000, p. viii). While this is a beginning of the most recent iteration of standards for the field under the name of technology education, there has been a history of the same and related communities attempting to do just what is done with the new standards, to identify the scope and sequence of content for technology education in schools.

Efforts to identify the scope and sequence of technology have been taking place throughout the ages as people have tried to teach each other about how to make and do the things that modify existing and create new environments for themselves. As humans used tools, materials, and processes to accomplish these changes, they have made many decisions about what and how to accomplish these changes. In order to teach another person about technology language had to be developed and transmitted in order to explain the skill and technique. Informally, teaching about technology has been a basic human endeavor since we first began to use tools.

Early forms of apprenticeships are thought to be one of the first efforts to educate others about specific technologies and most of the historical human efforts at teaching technology have been invested in this mode of transferring technical knowledge by direct explanation and demonstration. It was only until the eighteenth century that using objects was introduced as a means of improving education by Pestalozzi as what became commonly known and used in the United States as the "object method" of instruction and the nineteenth century when Salomon and Cygnaeus, Della Vos, Runkle, and Woodward began to look for ways to organize and teach techniques, technology, in a way that would permit more efficient and comprehensive methods of teaching the knowledge and skills associated with technology to students (Bennett,1926 & 1937).

It is really with the efforts of Salomon and Cygnaeus, Della Vos, Runkle, and Woodward that we see a beginning of the selection and sequencing of technical content for the purposes of instruction. Correspondingly, there was a growing recognition of the need to study technology as a subject in the schools for two purposes, both general education for all students and vocational education for those selected students preparing for jobs.

Early Industrial Education Practice

In the United States, the first formal programs for the study of technology appeared in the Manual Training School of Washington University in St. Louis and in the mechanic's school associated with the Massachusetts Institute of Technology. Each program of study headed by Calvin Woodward and William Runkle, respectively, drew upon the work of Victor Della Vos from the Imperial Technical School of Moscow and the Practical Technological Institute of St. Petersburg. Yet, each program took a very different philosophical approach to the value and purpose of instruction in technology. Woodward's purpose was to educate all boys, regardless of career aspirations, and Runkle's purpose was to educate mechanics with a better knowledge and grounding in the manual arts so that they could apply this knowledge and these skills to their jobs. This difference in thinking about the purpose of manual training is a difference in thinking that has passed through time because of the very nature of technology and the variety of roles and purposes that technological activity can serve.

Modern technology educators, who espouse the value of studying technology for all children and students, are more aligned with the Woodward philosophy in that he saw value in the study of technology for all students and saw the value of activity in the shops in relation to the abstract knowledge being taught in mathematics and other subject matter. Essentially, it was during a mathematics class on the topic of truncated cones that Woodward, an engineering professor, seeing the difficulty of his pre-engineering secondary students' comprehending the nature of a truncated cone, took them to the carpenter's shop on campus and had them make models. This was said to have initiated his thinking and eventual formation of the Manual Training School of Washington University (Coates, 1923). In setting up the high school curriculum for the manual training school, Woodward and his colleagues drew upon the curriculum work of Victor Della Vos and implemented courses similar to those being taught in Russia. Attributing ownership of the ideas to Russia, Woodward said:

> To Russia belongs the honor of having solved the problem of tool instruction. Others had admitted that practice in using tools and testing materials should go hand in hand with theory; but Russia first conceived and tested the idea of analyzing tool practice into its elements and teaching the elements abstractly to a class. In their hand, manual tool instruction has become a science (Woodward, 1887, p.277).

His use of the technical courses in school was not to prepare skilled craftsmen, but to provide a broad and general education for boys whom he expected to enter all manner of professions and trades. Woodworking, metalworking, and drafting were taught in the school in addition to the school subjects of English, mathematics, science, civil government, history, literature, and languages (Woodward, 1887 and 1898).

While Woodward was operating his manual training school and proselytizing on behalf of manual training, another European import, educational sloyd, came to the United States with Scandanavian immigrants. Developed in the early nineteenth century in Finland and championed, first, by Uno Cygnaeus with the founding of a normal school and, later, by Otto Salomon of Sweden, and nurtured in Scandanavian schools and normal schools, educational sloyd was a program of tool instruction designed for elementary and high school students which included both domestic and industrial arts and crafts. Gustaf Larrson, a Swede, who taught the techniques to elementary school teachers in Boston, introduced educational sloyd in the United States. Charles Kunou, Josef Sandberg, and Lars Erikson, Scandinavian immigrants, carried sloyd practice to other states such as California and Minnesota (Bennett, 1937).

As a school subject educational sloyd was a series of graded items from simple to complex for young children to make (Bennett, 1937). The name, educational sloyd, refers to the sloyd knife, a carving knife, that was used in order to fashion the simple household items such as garden plant markers, spoons, and hangers and became the term that referred to a much wider use and practice with tools. This version of tool instruction was truly created for the general education of young children and implemented by teachers during the late nineteenth century as activity-based instruction was beginning to gain popularity.

Also in the late nineteenth century, Emily Huntington, principal of the Wilson Industrial School for Girls in New York City, created a study of the kitchen and garden by having child-sized household tools and utensils created for her students. Her work led to the creation of the Kitchen Garden Association in 1880 to promote this kind of study for elementary school students. By 1884, this was dissolved in order to organize the Industrial Education Association, which was created in order to promote a more inclusive view of industrial education that included domestic economy and shop work for girls and boys (Bennett, 1937).

Another advocate for industrial education, Felix Adler of the Workingman's school in New York, stated his philosophy on the role and purpose of industrial studies in the schools:

> The salient feature of the new experiment is that it introduces what may be called the *creative method* into school education. The system of teaching by object lessons has long been familiar to educators. It is proposed to improve upon this system by giving lessons in the *production* of objects. The step forward taken by Pestalozzi, when he summoned teachers to desist from the vain work of teaching the names of things, marked a new epoch in the science of pedagogy. At present, still another step must be taken, viz, from the mere observation to the production of things as a means of acquiring knowledge; and the taking of this step will mark another epoch in pedagogy. (quoted in Bennett, 1937, p. 417)

Clearly, interest in and teaching about industrial education was gaining support.

By the end of the nineteenth century a need for teachers to teach a variety of industrial education subjects in schools, both elementary and secondary, was growing. Teacher education programs began to be created throughout the country. Industrial education or manual training programs were created in the new land grant colleges and universities such as The Ohio State University, the University of Illinois, and the University of Minnesota, and others spawned new teacher education institutions, as in Teachers College Columbia, founded to provide industrial education teachers for the new programs that were being started in schools (Bennett, 1937).

Coalescing Into Industrial Arts

After the turn of the turn of the century, from the nineteenth to the twentieth, John Dewey became a faculty member at Teachers College Columbia and had already been a strong advocate for activity-based education in elementary schools. He advocated including the study of the occupations, which he referred to as the activities of the kitchen and workshop.

> But out of occupation, out of doing things that are to produce results, and out of doing these in a social cooperative way, there is born a discipline of its own kind and type. Our whole conception of school discipline changes when we get this point of view. In critical moments we all realize that the only discipline that stands by us, the only training that becomes intuition, is that got through life itself. That we learn from experience, and from books or the sayings of others *only* as they are related to experience, are not mere phrases. But the school has been so set apart, so isolated from the ordinary conditions and motives of life, that the place where children are sent for discipline is the one place in the world where it is most difficult to get experience —the mother of all discipline worth the name (Dewey, 1900, pp. 30-31).

Dewey's advocacy of the study of the occupations helped to gain widespread acceptance of the study of manual arts and industrial arts in the schools (Zais, 1976). More important, Dewey advocated the social study of the occupations from an articulated philosophy of education. He was also clear that he did not advocate the teaching of skills and trades in schools for the purposes of training the labor force (Dewey, 1916). His view of the study of the occupations was to help students to learn from their active experiences.

Eventually, the growing interest in industrial education, the educational philosophy of Dewey, and the practices of educational sloyd combined to create a school subject called industrial arts that was designed for all students and implemented in the early grades, kindergarten through eight grade. Industrial arts was a term that had been gaining acceptance and use in the literature and was suggested by several prominent industrial educators as the appropriate term to use. Those who proposed this term thought of it as handwork for the purpose of being industrious rather than a study of industrial skills for the purpose of doing a job. They were searching for a term that would distinguish the field from vocational education (Bennett, 1937).

One of the first texts for teachers about industrial arts was *Industrial Arts for Elementary Schools* originally published in 1923 and written by Gordon Bonser and Lois Mossman (1928), colleagues of Dewey's at Teachers College Columbia in New York. They echoed a good deal of Dewey's ideas in the definition they gave to the study of the industrial arts.

> *The industrial arts are those occupations by which changes are made in the forms of materials to increase their values for human usage.* As a subject for educative purposes, *industrial arts is a study of the changes made by man in the forms of materials to increase their values, and of the problems of life related to these changes (*p. 5).

They, as Dewey, eschewed vocational education as a purpose for the industrial arts. And, in opposition to the manual training of Woodward, they created a different way of organizing content for teaching the industrial arts. From their definition of how humans make changes in the forms of materials, they focused on human needs and selected materials and products and organized them as the study of foods, clothing, shelter, utensils, records, tools and machines.

Unfortunately, practice and theory are often unrelated. Frequently, theory does not inform practice, and, in the case of the study of industrial arts, there were so many different influences and ideas of what it was being taught throughout the country that the evolution of the field throughout the twentieth century became a combination of ideas. The term of industrial arts became accepted as the appropriate term for the field and its practice in schools, both elementary and secondary, and, the definition proposed by Bonser and Mossman became the standard, but the curriculum retained was the original core curriculum set up by Woodward for manual training schools: drafting, woodworking, and metalworking with additional topics such as graphic arts, electricity, automobile mechanics, and plastics added as they became commonly used in industry and entered the awareness of the industrial arts community (Schmitt, Harrison, & Pelley, 1961; Olson, 1963).

The Evolution to Technology Education

By the middle of the twentieth century, frustrated by such things as the incongruence of theory and practice (Lux, 1979), the data showing the persistence of manual training content and practices (Schmitt, et al., 1961), growing discomfort with industrial arts as representative of modern technology, and the seemingly rapid change and development of technology (Towers, Lux, & Ray, 1966) industrial arts teacher educators began to plan, implement, and experiment with new ways of teaching industrial arts.

Proposals focusing on technology began to appear with *A Curriculum to Reflect Technology* (Warner, Gary, Gerbracht, Gilbert, Lisack, Klientjes, & Phillips, 1965) originally presented at an early, post World War II, American Industrial Arts Association Conference, leading the way. Warner and a team of his graduate students noted the dilemma of moving the industrial arts curriculum from handicrafts to technology and suggested the content organizers of management, communications, construction, power, transportation, and manufacturing. This plan further aligned the study of the industrial arts with the study of industry.

Following soon thereafter was a dissertation by another of Warner's students, Delmar Olson (1957), outlining technology content. Olson was one of the few industrial arts educators of the time to have his dissertation serve as the seed of a published book, *Industrial Arts and Technology*, (1963). Regarding content for industrial arts, he wrote, "In search of the technology for industrial arts subject matter the first step is to look at industry itself" (Olson, 1963, p. 61). In his book he focuses on modern industry as the means for classifying subject matter and suggested manufacturing, construction, power, transportation, electronics, and service industries, as well as, industrial research and management.

Thereafter, ensued a period of innovation, experimentation, and professional discourse amongst the community of scholars who were trying to improve and promote the study of industrial arts in the schools (Cochran, 1970). This period of curriculum debate lasted until the 1980s, when, confused by all of the different curriculum plans, the industrial arts supervisors from the state of West Virginia created a scheme to bring the curriculum specialists of the time together in order to synthesize their ideas into a plan for their state. This plan, *The Jackson's Mill Curriculum Theory* (Snyder & Hales,1981), became a national compromise and ended the period of experimentation in favor of a concerted effort to implement the proposal.

While there were many good curriculum plans created during the period of innovation (Cochran, 1970), the Jackson's Mill compromise featured the work and plans of only a handful of those who had experimented. Most influential regarding the *Jackson's Mill Curriculum Theory*, by the evidence of their ideas being incorporated in to the document, were the ideas and work of Donald Maley on the Maryland Plan (1973), Edward Towers, Donald Lux, and Willis Ray on the Industrial Arts Curriculum Project (1966), and Paul DeVore on his conceptualization for the study of technology (1980).

One of the first to actually experiment with industrial arts programs in schools was Donald Maley, from the University of Maryland, who created The Maryland Plan and, later, wrote a text of the same name (1973). He focused on the study of technology in the junior high school and implemented a new way of addressing industrial arts content. Of the three years of junior high school, he suggested the anthropological approach, an historical and cultural study of technology by making models of technological artifacts, for seventh grade study; the contemporary approach, group studies of line-production, for eight grade students; and the personal approach, personal and contemporary study of industry and its practice through research and experimentation and technical development. His graduates often implemented this program of study in the Maryland schools. Maley's work was much less involved with content definition than other innovators. His strength was in teaching method, a strong Deweyan philosophy, and a firm conviction in personally relevant curriculum.

While Maley was spreading his plan via the graduates of Maryland's teacher education program, a team of industrial arts teacher educators from The Ohio State University and the University of Illinois were awarded a federal grant to create a new industrial arts program. The project, called the Industrial Arts Curriculum Project, began with a document called *The Rationale and Structure of Industrial Arts Subject Matter* (Towers, et al., 1966). This document represented the thinking behind the eventual production of a new junior high school industrial arts program and the production of two textbooks. The content recommendations from this team for industrial arts were relatively simple, teach industrial technology as manufacturing and construction because when we look at how humans change materials into finished goods, they do it either in-plant (manufacturing) or on-site (construction). However, the real treasure of this curriculum was the rationale that they created in which they explained in great detail how they generated content for the field and provided a detailed list of manufacturing and construction content. To create the rationale and structure they consulted widely with educators and industrialists of all sorts from academe and business. One of the few oversights in this document was a lack of definitions for the detailed and often new content. They addressed content definition in the textbooks created for field testing and implementing the program. And, it was the creation and sales of the textbooks that helped to make this one of the most used innovative programs from that time period (LaPorte, 1980).

Also working throughout the same time period and gaining in influence was Paul DeVore who had taken up the theme of technology to study. He got groups of technologists, philosophers, and industrial arts educators together to study technology via small conferences and published several papers, monographs, and a textbook, *Technology: An Introduction* (1980). DeVore recommended that the study of technology should be organized by the adaptive technological systems of production, communication, and transportation, a way of looking at technology similar to what economists used. While DeVore promoted a view of content definition for technology, he was much more of an advocate of studying the relationship of society to technology, how we as humans create technologies, and how these technologies influence our environment. He advocated creating sustainable environments as one of the premier reasons for studying about technology. And, more than most technology educators of the time, he was interested in the philosophy of technology, studying, attending, and consulting with a wide variety of academics concerning the study of technology.

Compromising as Technology Education

When the group of industrial arts curriculum innovators was assembled in West Virginia, not all of the innovators were represented. Some of them had other commitments and could not make the meeting and some were not invited to the meeting. However, two strong personalities and representatives of innovation, Willis Ray and Paul DeVore were able to make the meeting and a few of Don Maley's colleagues and former graduate students represented his view. By this accident the die was cast for the eventual outcome of the compromise curriculum document, *Jackson's Mill Industrial Arts Curriculum Theory* (1981). The content outline that was created as a result of this meeting focused on the adaptive technological systems of manufacturing, construction, transportation, and communication, clearly a compromise between the recommendations of the IACP and DeVore's work. The suggestions for identifying content were taken from the IACP rationale, and a focus on society and technology was adopted from the DeVore work. Maley's work weighed in with a nod to studying the past, present, and future of technology.

After the Jackson's Mill document was created it became a rallying cry for the profession and was promoted by the American Industrial Arts Association (AIAA) and their related affiliate groups as the direction for technology education curriculum in the United States. By 1986, the AIAA changed its name to the International Technology

Education Association (ITEA) and rallied about teaching technology as recommended by the Jackson's Mill compromise. For the association, the compromise that ended debate about the nature of the field and its content, provided certainty in making recommendations to members and non-members alike about the definition and content of the field. The bigger problem was and had always been trying to initiate and sustain change in practice throughout the schools in the country.

Ten years after the Jackson's Mill conferences, a similar effort with a different cast of technology educators led by Leonard Sterry and Ernest Savage were called together to take a second look at the curriculum for the field. Savage had been promoting a different view of technology education in Ohio and had been working on a biotechnology textbook for the field. Interestingly, at the end of the series of three conferences, the resulting document, *A Conceptual Framework for Technology Education*, (Savage & Sterry, undated) retained much of the DeVore contributions to the Jackson's Mill curriculum, defined technology as "a body of knowledge and the systematic application of resources to produce outcomes in response to human needs and wants" (p. 7), touted the technological method as problem solving as the means of teaching technology, and listed content for the field as the technological processes of bio-related, communication, production, and transportation technologies. The document effectively removed the thinking of the IACP team and Maley. However, practitioners in schools were slow to take up the changes suggested in this document and many teacher educators did not stress this version of technology education.

After heading up at least two other standards projects for industrial arts and technology education which studiously avoided prescribing content for the subject, William Dugger (American Industrial Arts Association, undated and 1985) in conjunction with the International Technology Education Association sought funding from the National Science Foundation to create standards that were similar in nature to the newer mathematics and science standards that did prescribe content and significant changes for teaching that content in their respective subjects. The standards were preceded by a curriculum document entitled, *Technology for All Americans: A Rationale and Structure for the Study of Technology* (International Technology Education Association, 1996) in which technological literacy, a structure for the study of technology including processes, knowledge, and context, ways of teaching technology, and a call to action were discussed. Interestingly, with a preface definition of technology as "human innovation in action" (p. 16), the author(s) chose to define technological literacy as "the ability to use, manage, and understand technology" (p. 6). And, content was described as the universals of technology with *processes* as designing and developing, determining and controlling the behavior of, utilizing, and assessing the impact and consequences of technological systems; *knowledge* as the nature and evolution of technology, linkages, and technological concepts and principals; and *context* as information, physical, and biological systems.

After much consultation with members of the field, both teachers and teacher educators, standards were developed and presented to the profession in 2000 in the document entitled, *Standards for Technological Literacy: Content for the Study of Technology* (International Technology Education Association). With a decidedly new emphasis, the standards began with three standards regarding the nature of technology, four standards regarding the relationship of technology and society, three standards regarding design, three standards regarding abilities for a technological world, and, finally, seven standards regarding understanding the designed world. It is here that the usual content of the field has been listed and embellished with some new topics, medical, agricultural, related bio-, energy and power, information and communication, transportation, manufacturing, and construction technologies. This document signals a desire to transition the practice of technology educators with first emphasis on the nature of technology, design, and the interrelationships with society. These are the latest in curriculum prescriptions for technology education in the United States.

One of the persistent problems that has plagued technology educators and their practice has been the inertial resistance to changing classroom practice. While the discussion of technology as the content for the field has taken place over fifty years, it is still possible today to enter a local high school and find a woodworking class that would be not too much different from the days of Calvin Woodward. Although, not as much of the traditional manual training subject matter is being taught today, periodic surveys of practice do reveal this phenomenon (Dryenfurth, Custer, Loepp, Barnes, & Boyt, 1993). Nonetheless, as seen through this brief overview of what is being taught, technology educators continue to evolve their field of study in order to address contemporary technologies and the perceived needs of today's children. Underlying what is taught is why it has been taught.

III. Intellectual Roots

There is a curious similarity in the practical reasoning for promoting manual training in the United States schools of the late nineteenth century to the reasoning used today to promote technology education in our schools. In 1979 Woodward stated,

> Hence, as it is often said, nearly all our skilled workmen are imported. Our best machinists, miners, weavers, watchmakers, iron workers, draftsmen, and artisans of every description, come from abroad; and this is not because our native-born are deficient in natural tact or ability, nor because they are in point of fact above and beyond such occupations, but because they are without suitable means and opportunities for getting the proper training (quoted in Bennett, 1937, p. 348).

Today, we are still concerned about the need to import foreign technical expertise. While the reasons for promoting manual training and technology education may be similar across the years, the ideas, philosophies, and psychological knowledge that influenced the way in which people conceived of and created education about technology has evolved over the years.

Manual Training in Secondary Education to Improve the Faculties

The best historical record of the ideas which were used to support and form the study of secondary school manual training come from the writing of Woodward who was a prolific writer and speaker on the subject. There is good evidence through the historical record that he was responsible for promoting manual training in both secondary schools and in universities where he collaborated with other engineering faculty to initiate manual training teacher education programs (Ezell, 1982). In trying to establish manual training, Woodward was clear that it was for all boys, in the same way the study of mathematics, science, and languages was an important part of the education of all boys. Essentially, he worked to have manual training accepted as a subject for the general education of youth.

Working in an educational environment that was focused on reading and recitation and that was influenced by faculty psychology, Woodward spoke of manual training as compared to studying the sciences, "The application of the educational idea to mechanic arts is strictly analogous to its application to chemistry and physics" (quoted in Bennett, 1937, p.355). Faculty psychology, a belief that there were regions of the brain that controlled thoughts and functions and that those regions could be exercised in order to make people smarter, led educators to a reliance on reading, recitation, and drill. In the sciences this became the classroom experiment. In the languages, faculty psychology supported the teaching of language and the drill methods that were used for many years. So, with regard to manual training, Woodward wrote,

> The idea of a school is that pupils are to be graded and taught in classes; the result aimed at being not at all the objective product or finished work, but the intellectual and physical growth which comes from the exercise. Of what use is the elaborate solution in algebra, the minute drawing, or the faithful translation, after it is well done? Do we not erase the one, and burn the other, with the

> clear conviction that the only thing of value was the discipline, and that that is indestructible?
>
> So in manual education, the desired end is the acquirement of skill in the use of tools and materials, and not the production of specific articles: thence we abstract all the mechanical processes and manual arts and typical tools of the trades and occupations of men, arrange a systematic course of instruction in the same, and then incorporate it into our system of education. Thus, without teaching any one trade, we teach the essential mechanical principals of all (quoted in Bennett, 1937, p. 356).

Woodward was determined that the predominant teaching methods of the day which had been influenced by the predominant view of learning, faculty psychology, would be the same for manual training as it was for the rest of the school curriculum. While he recognized that there were critics who advocated constructing projects of immediate utility, he saw projects as having a limited role in manual training, not to interfere with the goal of teaching a wide range of knowledge and skills associated with constructive work that was organized into a series of graded activities that ranged from simple to complex and were not finished goods, but throw away tool exercises. At the end of a student's career, as a senior, some projects of utility such as engines were construct, but only after April when the abstract exercises were finished (Woodward, 1987).

Advocating manual training at an 1884 National Education Association meeting by stating that manual training would be of value, hypothetically, with no industry and trades in the country, Adler more clearly stated a faculty psychology argument,

> I should plead for it then, as now, simply because of its broadening, humanizing effect; because it quickens into activity certain faculties of human nature which too commonly lie dormant; because, instead of the present one-sided development, it is a step further in the direction of that all-sided development which is the ideal in education (quoted in Bennett, 1937, p. 364).

The main argument of both Adler and Woodward was that manual training addressed critical educational needs not addressed by other subjects in the school curriculum. Woodward summed up his argument with the often repeated phrase, "Put the whole boy to school" (Bennett, 1937, p. 367) to stress educating both the mind and the hand through activity.

To further explain that manual training educators of the day meant that the subject was intended to address both cognitive and psychomotor education needs of youth, Butler, then president of the New York College for the Training of Teachers, soon to be Teachers College Columbia, stated,

> If the term manual training is used in antithesis to mental training, it is wrongly understood. Manual training, as I use the term, is mental training. It is mental training by means of manual training. It is included in the psychologically determined course of study because it reaches important mental faculties which no other studies reach. It is also a most valuable and important stimulus to the receptive faculty of observation. The child can neither draw

> accurately nor construct correctly unless he observes acutely
> (quoted in Bennett, 1937, p. 369).

From the beginning of manual training in the school, those who conceptualized it and implemented it in schools saw it as an integral part of the curriculum because it addressed the psychological needs of the learner by providing activities and experiences that were not being provided in the standard school curriculum. They saw manual work as an important component of all learning by recognizing the relationship between activity and knowing.

Those who were manual training educators saw a clear purpose for the subject in the schools. Often, it was others who muddied the waters with arguments regarding the value and purpose of manual training. For example, Jane Addams (1969) and other social workers of the time advocated manual training as a means of providing an appropriate education for the immigrant children who were flooding into the great cities of the day. School administrators then, as today, often looked to and implemented technical courses of study in order to address the needs of problem students, such as blind, deaf, delinquent, and ethnic minority students through establishing industrial schools (Bennett, 1926). The contrast of industrial schools as reformatories to manual training as college preparatory education gave pause, then, and still characterizes the study of technology as not for college bound students to many educators and parents today.

Industrial Education for all Students in Elementary Schools

In the elementary schools while handwork was also catching on and being proposed as an integral part of the curriculum for all students, the reasons for the interest in it were similar to those arguments promoted by Woodward for secondary manual training. Trade training was eschewed. As the practice and experience with handwork in elementary schools grew, a new direction was taken, and, that direction was undeniably influenced by progressive education.

Bennett (1937) recognized that with the formation of the Industrial Education Association in 1884, more women were brought into industrial education. These women and men working together and their interests and voices may very well have shaped the discourse about industrial education in the elementary schools in a different direction (Zuga, 1996). Reacting to criticism of the use of the word "industrial" in the name of the association and its linking to teaching trades in schools, Washington Gladden countered with

> There is an industrial training which is neither technical or professional, which is calculated to make better men and better citizens of the pupils, no matter what calling they may afterward follow; which affects directly, and in a most salutary manner, the mind and character of the pupil, and which will be of constant service to him through all his life, whether he be wage worker or trader, teacher or clergyman. The training of the eye and of the hand are important and essential elements in all good education. (quoted in Bennett, 1937, p. 414).

The efforts of educators who were working at the elementary school level focused more on the "industrious" definition of the term, rather than the "industry as business" meaning. This is further explained by Dutton's description of the role of handwork instruction in the New Haven, Connecticut schools.

> It is the industrial and industrious spirit that we want in our schools, and in the community as well, so that honest labor may be not only respectable but honorable. It must be counted a misfortune that popular intelligence does not grasp the principles which underlie an education which begins in kindergarten and carries the industrial and productive ideas through all grades (quoted in Bennett, 1937, pp. 423-424).

They also saw the subject as an extension of Froebel's ideas regarding creativity in the kindergarten and sought to extend them through the elementary grades as means of learning other subject matter. In a report of the Workingman's School in 1887 Bamberger, specifically addressed this.

> Pupils of the lowest classes work in clay, using compasses, rulers, and blunt knives; they draw upon the clay, and afterwards cut out the simple plane figures; acquiring in this way the elementary ideas of geometrical forms. Pupils next above these grades use pasteboard as material, and sharp knives, awls, etc. as tools. The work consists of a series of exercises in stereography, the various geometrical solids being drawn in flat projection, and afterwards folded up and glued into shape. Passing above this grade, pupils next work in flat wood, using the necessary tools, including the bracket saw. Mensuration of areas is taught by this means. . . At every stage of the course, the nature and limitations of the materials used, the capacities of the tools employed, and the physical and mathematical properties of the objects constructed, are impressed upon the mind of the pupil; and a firm foundation is thus laid for the future study of the natural sciences, and an intelligent understanding of abstract mathematics (quoted in Bennett, 1937, p. 418).

He continued in his report to discuss the making of a steam engine and the creation of apparatus to study physics, further illustrating the early thinking on the integration of mathematics, science, and technology education.

Gradually, the rigid system of tool instruction that had been implemented in secondary schools was modified in the elementary school. Educational sloyd imported from Sweden focused on individual instruction, recognizing the differences between and among students rather than the whole class instructional methods used by the Russian system. Toy making in the lower elementary school grades and making scientific apparatus in the upper elementary school grades became a modification of the sloyd curriculum as many manual training educators began to move away from rigidly adhering to models to be made. With the influence of the arts and crafts movement in society, particularly in art, architecture, and design, the idea of design gained strength in the schools and individually designed products began to appear in school workshops (Bennett, 1937).

Advocates of industrial education were beginning to realize another value inherent in the subject. It was an idea that was also taking shape in the psychological work of Piaget and Vygotsky as they experimented in order to identify how people learn.

> In a magazine article on 'The Thought Side of manual Training,' published in 1902, he [Arthur W. Richards] said, 'The arts of industry furnish a motive thought and answer, as nothing else, the requirements for a basis for the manual work in our schools; because, more adequately than any other division of human activity, they represent that which has been evolved by the joint efforts of brain and hand.' (Bennett, 1937, p. 440)

In this recounting, both the interest in activity as the stimulus for thought as advocated, later, by both Piaget and Vygotsky (Piaget, 1969; Kozulin, 1996) is stated in the purpose of manual activity in the schools. The view expressed here also gives more definition to the frequently used expressions of teaching both the hand and the eye and educating the whole child. While it is a glimmer of an idea, it points to the need to look at the role of activity in learning.

Presaging practice today, early evidence of teaching design and using design as a method of instruction was apparent in the same article by Richards. In referring to his discussion of thought and manual training, Richards illustrated the kind of activities that the elementary school children had completed.

> He accompanied his statement with illustrations showing the solutions of problems in mechanics and engineering by boys in the elementary schools. These included models of a waterwheel, a windmill, an airship, girders, devices for testing the strength of materials and construction elements, and such things as a mechanical shovel, a power derrick, and a bridge. He described the method of procedure in such problems in this sentence: 'The purpose of the project, the function of its parts, and the principle upon which it worked were discussed, leaving the pupil to bring a plan for the same and work it out as his own business.' (Bennett, 1937, p. 440)

Here is one of the first references to teaching by design. This was not a prescription to use throw-away exercises, nor teacher chosen and modeled projects, but problems chosen by students to be solved by making a product. The question of why this emphasis on design was not sustained throughout the years of practice in industrial arts begs to be answered. Bennett (1937) comments that there weren't enough teachers trained and capable enough to implement design as a method. It may also be that it was an elementary school approach to teaching, rather than a secondary school approach, since the influence of the Russian method of tool instruction was stronger in the upper grades.

Clearly, innovation in subject matter and method of manual training were implemented in elementary schools. And, at the beginning of the twentieth century, the influence of progressive educators with regard to innovation in industrial arts was evident.

Industrial Arts and the Elementary School

The era of the progressive educators issued in a concern for the reconstruction of society. The basic idea was that through education we could improve our society by providing activities that would enable children to experiment with authority and problem solving in the school for the purpose of teaching children how to lead and how improve upon their conditions and society. These ideas were expressed in the writings of many of the progressive educators, Bode (1933) explains social reconstruction as a "continuous reconstruction of experience" (p. 19) in daily school practice with the following examples:

> This reconstruction of experience, if it is to have any significance, must take the form of actual living and doing. Consequently the school must be transformed into a place where pupils go, not primarily to acquire knowledge, but to carry on a way of life. That is, the school is to be regarded as, first of all, an ideal community in which pupils get practice in cooperation, in self-government, and in the application of intelligence to difficulties or problems as they may arise.

Dewey was one of the primary architects of this thinking. In *Democracy and Education* (1916) he began to outline the role of social reconstruction in a democracy by writing that education was "to shape the experiences of the young so that instead of reproducing current habits, better habits shall be formed, and thus the future adult society be an improvement on their own" (p. 79).

Working at Teachers College Columbia and progressive educators, themselves, Bonser and Mossman held similar views on social reconstruction as Bode, Counts, Dewey, and Kilpatrick (Petrina & Volk, 1995a). Working at a university with a tradition of manual training education, they saw the way in which a study of manual training could be a curriculum for social reconstruction and, these ideas began to appear in their writing regarding industrial arts. As a primary architect of industrial arts during the early twentieth century, Bonser promoted a social reconstruction role for the field.

> Bonser advocated a mission of social reconstruction for the schools, much like Counts, Dewey, Kilpatrick, Mossman, and Bode (Bonser, 1931). For these educators, industrial education stood to be a relevant and central aspect of social reconstructionism, and therefore a highly contested curriculum area. In effect, Bonser's view of industrial arts reflected complex interpretation of technology, sensitivity to social injustices, notions of empowerment, and reconstructionist thought.
>
> Bonser's views on industrial arts continued to evolve in coherence, complexity, and intent through the final years of his life. One of Bonser's last definitions of industrial arts attests to his increasingly complex views on the subject. By 1930, industrial arts was 'the study of sources of materials, factory organizations, inventions, employer and labor cooperation, distribution of products, and regulative measures to secure justice alike to producers and consumers' [Bonser, 1930, p.2] (Petrina and Volk, 1995a, p. 28).

This social reconstruction view of industrial arts saw it as a subject that had a central role to play in helping students to understand and reshape the society of which they were members. When Bonser advocated the study of factory organizations and employer and labor cooperation, it was not to uphold the status quo. It was to critically examine the practices of industry and society so that students as future citizens could go about the business of improving society. It is no wonder that some industrial arts educators began to see that design was a viable teaching method and that students could be given the power to create through an industrial arts that was embedded in a social reconstruction perspective.

These ideas were echoed in the work of others interested in and promoting the study of industrial arts in the elementary school. In writing about teaching by the use of projects, Hennes (1921) encapsulated the social reconstruction perspective.

> There are certain social ideals and skills absolutely necessary in order to live unselfishly and helpfully in society with their fellows. Our children must learn how to cooperate. They must learn the spirit of mutual helpfulness. They must come to appreciate fair play, and thus become unselfish in their dealings with others. They must, in particular, learn to be truthful (p. 137).

Elementary school industrial arts educators of the time were also well aware of the role of industrial arts with regard to learning.

> Problems in construction and investigation may, and should, involve methods of thinking, judging of the value of thought, judging the forms of procedure, and judging of results. To include these, however, in more than a relatively trivial degree, the activities must include the designing and planning aspects of the work. They must represent the real expression of thought, or a thinking process by which ideas are clarified and enlarged (Bonser & Mossman, 1928, pp. 46-47).

Through arguments like these industrial arts educators in the elementary schools expanded the ideas of those in manual training and industrial education who advocated teaching both the hand and the eye. And, the ideas of educators like Bonser and Mossman, again, were in concert with the ideas of Dewey regarding the role of experience in education (Petrina & Volk, 1995b). For example, Bonser and Mossman (1928) wrote:

> The new processes in the construction must be considered in relationship to their purposes. As the questions are raised and answered, meanings are realized more fully through the actual constructions and the judgments of results than by merely talking and reading about the problems, or even by looking at pictures or models of objects considered. There is something of meaning and significance which attaches to experiences of actual, practical participation which is not realized without it. The realities of experience make for genuineness and permanence of meaning not realized from the mere getting of information about facts and relationships. To one who has spun a small quantity of yarn, who has woven a small rug, who has constructed a house or a piece of

> furniture, who has made a piece of pottery, and who has followed through the different illustrative methods of food preservation—to such a person all of the industrial activities corresponding to these have a fullness and warmth of interest and meaning not possessed by one who has not had these experiences. (p. 47).

The ideas expressed above are the manifestation in industrial arts of the philosophy of Dewey with regard to the meaning and need for experience in education. In 1925 speaking of experience and philosophy, Dewey wrote:

> It is 'double-barrelled' in that it recognizes in its primary integrity no division between act and material, subject and object, but contains them both in an unanalyzed totality. 'Thing' and 'thought' as James says in the same connection, are single barreled; they refer to products discriminated by reflection out of primary experience. (Dewey, 1929/1971, pp. 10-11)

Early advocates for industrial arts in elementary school education as progressive educators picked up the threads of the manual training argument of combining the hand and the eye (Woodward, 1887) for the purposes of education and, with further clarification from pragmatic philosophers such as Dewey, they strengthened the argument for activity in education. Their arguments were in concert with the work that was being done by Piaget (1969) and Vygotsky (Kozulin, 1996) at about the same time period with regard to the psychology of activity in learning language, as well as, the creation of language and new knowledge. The philosophy of pragmatism, the learning psychology of Piaget and Vygotsky, and the educational movement of the progressives converged to support and create a forward looking ideology of industrial arts. Unfortunately, it was never fully realized during the coming years (Petrina & Volk, 1995b).

> A formative vision of industrial arts was shaped through expressions of social reconstruction, experience, and unity, sustaining a movement that challenged contemporary models of vocational and conventional education. With this vision and ideals, industrial arts was conceptualized to stand squarely within general education as a socially vibrant movement for expressive individualism, solidarity, and social change. In historical perspective, industrial arts as fashioned by Dewey, Bonser, Mossman, and other liberal-Progressives was not a path taken by the profession (p. 33).

With regard to the interpretation of Dewey by the industrial arts community, Olson (1963) wrote that the community did not think deeply enough about what Dewey was saying.

> Dewey's concern for the scientific method in education was implemented by a methodology for teaching founded on his doctrines of interest and experience. His influence on the industrial arts curriculum has probably been less than his influence on its teaching procedures. Those in industrial arts usually settled for the *learning-by-doing slogan.* Had they probed his philosophy deeply enough to find its key concepts for education, they might have been moved to vast curriculum changes (p.22).

Post Social Reconceptualism Industrial Arts

With the work of Bonser and Mossman, the purpose and goals of industrial arts were being shaped to serve a role in social reconstruction. However, this was not a view shared by everyone regarding the nature of the field (Olson, 1963; Petrina & Volk, 1995b). Fractionalization of thinking about the role and purpose of the field was evident in the very fact that the name of the field was in contention. Manual training, industrial education, manual arts, handwork, industrial arts, and other more obscure terms were used by administrators, teachers, and the public to describe their versions and their ideological ideas about what was taught in the schools. Moreover, when a study was conducted regarding the names used for the field and suggested solidifying the use of industrial arts as the name, that appears to be all that was agreed upon, the name, and not the practice (Olson, 1963). Variations of practice ranging from the tradition of manual training tool instruction to social reconstruction influenced design as method were in play.

One of the prominent industrial arts educators of the early part of the twentieth century who should have been influenced by the social reconstruction curriculum orientation of the faculty of Teachers College Columbia was William Warner, a leader and innovator in industrial arts education, responsible for maintaining a separate identity from vocational education with the founding of the American Industrial Arts Association and promoting professionalism in the field with the founding of the honorary society, Epsilon Pi Tau. After graduation from Teachers College Columbia he found a job at The Ohio State University in a college of education that was renown at the time for having a reconceptualist and progressive faculty. From his growing and influential platform, Warner began to promote, with his graduate students, a broader curriculum for industrial arts which was inclusive of technology. Warner had been prepared to take up the progressive mantle and he was in an ideal university setting to continue the work of his mentors from Teachers College. He did not, however, display a strong commitment to a social reconstruction perspective and did not create the kind of arguments created by Bonser in the literature. Instead, Warner espoused a socio-economic role and curriculum for industrial arts and went so far as to say that Bonser had proposed and demonstrated at the Speyer School the "industrial-social theory" (Snedden & Warner, 1927, p. 7; Olson, 1963)

Warner was an enigma in that he espoused a very conservative political philosophy, especially after he returned from World War II. If he had ever been a social reconstructionist prior to the second world war, it is difficult to imagine how he could have maintained that philosophy after the war based upon his own activities and pronouncements. By the 1960s, as a man who had joined a notoriously liberal faculty of reconceptualists, he had taken a full page advertisement in the university's student newspaper to list the names of fellow faculty whom he deemed to be communists (Gloekner, 1981). Perhaps, it is because of his essentially conservative nature that he was able to promote a view of industrial arts as a technology based field of study and ignore the social prescriptions for the curriculum which were so evident in the work of Bonser and Mossman (1928). With the untimely death of Bonser in 1931, the field had lost a powerful voice for social reconstruction as a goal of industrial arts (Petrina & Volk, 1995a).

Those who continued to represent the progressive ideals in industrial arts remained focused on the elementary school curriculum and practice of industrial arts but, slowly, their voices were diminished as other ideals and ideologies influenced industrial arts (Zuga, 1996).

> As industrial arts evolved, it became apparent that early interest in providing subject matter for all children, boys and girls, was not being practiced--the common pattern of industrial arts for boys and home economics for girls became set. In the literature for the field, prescriptive theory for content became more narrowly focused on woodworking, metalworking, and drawing in secondary schools, while the inclusive curriculum of elementary schools focused on weaving, sewing, clay modeling, woodworking, block building, and paper construction (Weicking, 1928) and/or foods, clothing, shelter, utensils, records, and tools and machines (Bonser and Mossman, 1923). This split may be partially due to the association with vocational education in collegiate and secondary education and the loss of the female elementary educators' voices. (p. 31)

The pattern of curriculum for the industrial arts continued as the manual training curriculum of woodworking, metalworking, and drawing with additional topics added over the years. Curriculum advice and prescriptions for industrial arts such as using task analysis to identify curriculum and creating job sheets came from vocational education texts (Selvidge, 1924; Fryklund & Selvidge, 1946; Fryklund, 1956; Olson, 1963) as many of the Midwestern institutions that prepared industrial arts teachers prepared vocational teachers in the same teacher education program and courses (Olson, 1963; Zuga, 1991).

> While the texts may state that the purposes and time length of industrial arts classes in the schools were different than the vocational classes, every other prescription for curriculum planning and classroom practice was a prescription for planning vocational education by using task analysis (Fryklund, 1956; Fryklund & Selvidge, 1946; Selvidge, 1923). Naive teacher education students who were not tuned into the different purposes of general education practice versus vocational preparation were often not capable of creating a school practice that was anything more than a scaled down copy of vocational education, because that is what they were taught to do. Those who were more independent were either driven to search for more guidance or were able to break free of their teacher education prescriptions, but those teachers were not the majority (Zuga, 1996, p. 33).

Federal funding for vocational education reinforced the trend towards combining vocational teacher preparation with industrial arts teacher education as university faculty looked to gain efficiencies with the use of laboratories and faculty. In this atmosphere, the ideology of industrial arts as general education was stated but was mostly ignored in curriculum planning prescriptions.

It could also be said that the battle to implement industrial arts in the schools' curriculum had been won, for the time, and that the professionals in the field turned to the business of preparing teachers and slighted the intellectual purpose of industrial arts in the schools. During the period the goals of industrial arts strayed not far from manual training origins.

> In 1928 Warner did an extensive study about the goals of industrial arts by looking at books, courses of study, periodicals, government bulletins, and the annual reports of the National Education Association. These goals reflect a traditional view of industrial arts highlighting career exploration and vocation, consumerism, and skill development. The vestiges of the influence of Woodward's (1898) version of manual training are evident in the goal of developing fine motor control. Some of the goals were as follows:
> *Career Exploration and Vocation:* exploratory shop and drawing courses for the detection, discovery, or tryout of interests and aptitudes; avocational and prevocational purposes, preparing for a future industrial occupation;
> *Critical Consumerism:* making more intelligent choosers and users of the products of industry;
> *Skill Development:* develop household mechanics; develop mechanical intelligence through experience in hand work where fairly high levels of skill in the use of various tools and materials are the chief emphasis;
> *Physical Development:* develop coordination of "hand and eye" by making things (Zuga, 1989, p. 36).

Over the course of the century, change in the goals of the field did not progress rapidly, but evolved slowly over time. Table one (Zuga, 1989, p. 39) illustrates the slight change in industrial arts goals over the course of the twentieth century. It indicates that the intellectual roots of manual training persisted through most of the century in the formal curriculum documents of the field. Also indicated is the influence of those who advocated the study of industry and/or technology as the content base of industrial arts during the period of innovation that took place mid-century.

Table 1
Evolution of Industrial Arts/Technology Education Goals

Categories of Goals	Twenty Year Time Periods				
	1928	1948	1967	1980's	
Physical Development	X				
Integration of Disciplines		X			
Intellectual Processes		X	X	X	
Career and Vocation		X	X	X	X
Critical Consumerism	X	X	X	X	
Skills Development		X	X	X	X
Industry and Technology			X	X	

Curriculum Innovation as a Focus on Technology and Industry

It was the middle of the twentieth century when curriculum became the predominant concern of the profession and, it was Warner and his students who led the way with a focus on industry and technology as the basis for industrial arts curriculum.

> *Functionally,* Industrial Arts [sic] as a general and fundamental school subject in a free society is concerned with providing experiences that will help persons of all ages and both sexes to profit by technology, because all are involved as *consumers*, many as *producers*, and there are countless *recreational*, opportunities for all. (Warner, 1965, p. 41).

Reprinted in a *Curriculum to Reflect Technology* and originally published in a 1947 issue of *The Industrial Arts Teacher*, Warner's definition identifies him as an advocate of basing industrial arts curriculum on industry, technology, and the economy. Moreover, his focus on the subject is far from the social reconstruction perspective of Bonser and Mossman in that he sees consuming, producing, and recreating in a free society as the main purpose of industrial arts. The goals of reforming and improving that society are not ever mentioned in his discussion of the definition of the field which he offers as a replacement for Bonser and Mossman's (1928) definition so that the definition could be "stated in the context of application or program" (Warner, 1965, p. 41). Warner had taken the industrial arts from a social reconstruction perspective to a socio-economic perspective that dwelt in the capitalistic functions of production, consumption, and recreation.

Olson followed with his dissertation (1957) under the guidance of Warner and his book, *Industrial Arts and Technology* (1963) and enriched the concept of technology and industry as the proper base for the school subject of industrial arts.

> A broad interpretation of industry considers it as a system of enterprises for the development, production, and utilization of material goods and services by which a people gain control over their physical environment. Through rather logical deduction, then, technology becomes the science of industry. As such it becomes the systematized knowledge derived from study, experiment, research, development, design, invention, and construction with materials, processes, products, and energies. Put another way, technology can be considered as the field of systematized knowledge derived from the study of nature, the principles and practices, the products, the services, and the energies provided and employed by industry. Consequently, we study industry to learn about technology, its techniques, skills, processes, products, services, and occupations. We find meaning and significance in technology as we study the contributions of industry to man's control over his physical environment and the ends to which he uses this control (Olson, 1963, p. 55)

There many important points in this passage from Olson which clarify the role of technology and industry as the basis for the study of industrial arts. The overall tone of the definition is focused on production and the economy and it has omitted the emphasis on the problems that Bonser and Mossman (1928) saw could result from human choices with regard to the use of technology. And, in the text, Olson refers to technology as the great benefactor and states that if we understood the meaning of technology, we would be able to understand how technology benefits humankind. He even goes so far as to say that labor strife would be eliminated if laborers felt that they were "part of a master plan directed to the elevation of all men through technological development and in the process was being elevated himself, he would likely see his employer as a partner" (p. 58). He sees humans in control of technology and not, as many later began to see technology out of control (Winner, 1977). The focus is on industry and the business of production and gone is the view of industrial as being industrious. Handwork is relegated in his text to elementary schools and young children while in the serious business of industrial arts at the secondary school there would be machines of production just like in industry. Enterprise, running a business, is featured and, as Olson looks to industry as a role model for curriculum, criticism of that business is omitted. And, as in modern industry, knowledge is systematized through research and experiment. These are significant changes in the literature dealing with the definition, goals, and purposes of industrial arts subject matter.

Given the backdrop of society and culture in the United States during the 1950s and 1960s, it is easy to see how the leaders in industrial arts education began to distance themselves from the work of Dewey and social reconstruction. Dewey had come into question during the McCarthy era and his ideas were not in favor. Tradition in industrial arts leaned towards industry as a result of many years of alliance with vocational education. Even Warner and his followers, who fought to establish an industrial arts organization separate from the American Vocational Association, did not separate themselves from industry and corporate America, nor did Warner and Olson's students who became the next generation of leaders in industrial arts. Maley, DeVore, Lux, and Ray, all had ties to William Warner and his influence by either being his students, being students of Warner's students, or working with him. So, as innovation in industrial arts took hold, many of the ideas of Warner and Olson made their way into the thinking and prescriptions for the field by the leaders who created their own curriculum plans and collaborated on the Jackson's Mill compromise.

Influenced by Hornbake, a student of Warner's, to whom he gives credit for developing his philosophy as his professional inspiration, Maley was the most Deweyan of the new generation of leaders to emerge. His definition of industrial arts retains some of the social reconstruction words of the Bonser and Mossman definition and the actualization of Maley's curriculum, The Maryland Plan, focuses on the personal relevance aspects of Dewey's educational philosophy. However, Maley was on the same page as the rest of the field, focusing, first, on technology and industry. "Industrial arts, as a curriculum area, is defined as: those phases of general education which deal with *technology*— its evolution, utilization, and significance; with *industry*— its organization, materials, occupations, processes, and products; and with *problems* and *benefits* resulting from the technological and industrial nature of society" (Maley, 1973, p. 3) is the way in which he defined industrial arts. It is interesting that he added the "benefits" to the phrase regarding the problems resulting from our use of technology.

In *A Rationale and Structure of Industrial Arts Subject Matter* (Towers, Lux, & Ray, 1966), the authors never doubted the Warner and Olson industry and technology basis for industrial arts subject matter. In their assumptions for the project that they listed, the focus on industry and the systematizing of knowledge is acknowledged. A unique and unexpected aspect to their thinking was that they were influenced by the concept of praxis. Cited in the text and references of the rationale are two Marxist philosophers of technology, Kotarbinski and Skolimowski, and four of their texts which deal with praxis, praxiology, and technology. Interestingly, references to one of the originators of the concept of praxis and his intellectual influence on Kotarbinski and Skolimowski, Karl Marx, are absent from their text. Nonetheless, the concept of praxis had been a topic of study that was Marxist and had much more of an interest to Eastern European scholars in all fields. A currently popular learning theorist, Vygotsky, can be included in that group as the Marxist ideas about praxis influenced his study of activity in learning (Daniels, 1996). Marxist theory concerning the role of work and labor led many Eastern European scholars to focus more study on the role of technology in all phases of life and learning. What was surprising was that the Industrial Arts Curriculum Project team decided to use praxiology as a concept in their rationale, defining it as follows.

> Praxiology (technology) is the product of the organized, disciplined study of the practices of man. It has to do with all of the practices which ultimately affect the individual and social human behavior. Praxiological (technological) knowledge is not simply that formal, descriptive, and prescriptive knowledge which relates to the solution of practical problems; it is not practice *per se*. Praxiology (technology) is a distinct, developing body of knowledge (principles) which is being tested in practice and is or is likely to be codified. . .This Project [sic] is vitally concerned with conceptualizing a structure for that division of praxiology (technology) which is the appropriate concern of industrial arts; that is, industrial praxiology (technology) (Towers, Lux, & Ray, 1966, p. 39).

Instant rejection by the profession and time has morphed their concept of praxiology to technology, an idea that must have been on their minds due to the use of the term, technology, in parentheses at every instance of the use of the term, praxiology. This project became know as focusing on industrial technology. Those who adhered to the ideas inherent in the IACP argued for an industrial focus in industrial arts, arguing that the tradition of the field was within industry.

Having studied with Olson as a student at Kent State University, DeVore went forward to distinguish himself as a proponent of technology as the content base for the field. Like Olson, DeVore saw the value in people understanding technology for the purpose of controlling it.

> There is a definite relation between the control of technical systems for human purposes and the level of education—knowledge and know-how—of the behavior of the systems. The control of any process presupposes an understanding of the behavior of the process and the function of variables that affect the process.
>
> In a democratic society the education of citizens for their role as decision-makers and controllers of technical systems should be one of the primary functions of education (DeVore, 1980, p. 327).

Unlike Olson, DeVore has been more of an advocate of creating a sustainable environment even if that means questioning industry and creating viable alternatives which would help to sustain the environment.
He was very well aware of the growing body of technology literature and championed the study of technology as a means for people to overcome the problems associated with our use of technology. Continuing the idea of systematizing our thinking about technology, DeVore (1980) saw the interrelationship of systems in a Ven diagram that embedded technological, ideological, and sociological systems in a larger ecological system as the content for the study and teaching of technology. It is fascinating that he saw technological systems in the terms of economists as production, transportation, and communication, yet, also re-introduced into the literature of the field, ideology and sociology with respect to the study of technology. Although, his return of a social concern in technology education did not approach the social reconstruction ideology of Dewey (1916), Bonser, and Mossman (1928).

As industrial arts educators experimented with innovative plans for the subject matter, most of them could be classified as either focusing on industry, industrial technology, and/or technology. And, as time progressed, the advocates for a study of technology grew in numbers. By the time that the end of the Twentieth Century was approaching, two curriculum documents, more noted for creating a compromise than providing new insights and intellectual merit to the study of technology were created. The *Jackson's Mill Industrial Arts Curriculum Theory* (Snyder & Hales, 1981) and *A Conceptual Framework for Technology Education* (Sterry & Savage, undated) gave the profession, especially the professional association, the International Technology Education Association, the platform to declare technology as the subject matter of industrial arts and to change the name of the field to technology education and to incorporate technology education into the name of the association.

In order to try to address the outdated practices in schools of teaching woodworking, metalworking, and drafting, a national emphasis on the compromise content of manufacturing, construction, transportation, and communication ensued. The content represented the recommended content organizers from both the Industrial Arts Curriculum Project (Towers, et al., 1966) and DeVore's (1980) conceptions of technological systems. Systems thinking was embedded in the documents as the technological systems were referred to as human adaptive systems, a way that DeVore (1980) had referred to them.

Growing in popularity, again, amongst members of the profession, was the belief in design and problem solving as a means for teaching people about technology. A small flame of this method had remained alive since its inception in the early part of the century in the United States and had received much more credence in the United Kingdom as British design and technology educators advocated and implemented a design approach to studying technology. Slowly, their ideas returned to our shores with the exchange of scholars and gained a new foothold in the thinking of technology educators. The idea of using problem solving as the method of instruction was given voice in the Savage and Sterry conceptual framework. "As such, in its education counterpart, the Model for Technology Education [referred to in earlier text as The Technological Method Model], students will identify problems or opportunities utilizing the problem solving method, selecting the appropriate resources and employing technological processes to produce outcomes for which they will assess the consequences" (Savage & Sterry, undated, p. 20). Once again, however, the social emphasis re-introduced by DeVore was removed from the definition of technology education provided in this document.

> Technology education has been defined as a body of knowledge and the systematic application of resources to produce outcomes in response to human needs and wants. Technology education must allow individuals to understand technology in the context of the world in which they live and interact. Therefore, technology education is the study of technology and its effect on individuals, society, and civilization (p. 20).

This definition went so far as to depersonalize people as individuals and created a linear view of the role of technology in our society focusing on the control that people have to produce outcomes and consequences in response to their needs and wants. Interactivity was not evident in the models presented and societal concerns, although mentioned in the document, had receded, once again.

The end of the Twentieth Century brought the most recent standards project for technology education. By now, technology as the content base for the field was accepted by most of the profession and the job at hand was to create standards for implementing the study of technology in schools. What was new for the field was a partnership with other agencies such as the National Science Foundation and The National Aeronautics and Space Administration as the impetus and the source of funds for the standards. The very existence of the standards reflect the changing politics in that the focus on standards, and, eventually, evaluation based upon the standards, was and remains a growing trend in the United States. In order to see themselves as a part of the educational system, technology educators embarked on the prescriptive practice of creating standards for teaching technology as a prelude to being able to evaluate the success of that effort.

Important ideas for technology educators in *Technology for All Americans: A Rationale and Structure for the Study of Technology* (Technology for All Americans Project, International Technology Education Association, 1996) were the refocusing of technology as a universal concept with processes, knowledge, and contexts of application.

> Technology is human innovation in action. It involves the generation of knowledge and processes to develop systems that solve problems and extend human capabilities. As such, technology has a process, knowledge, and context base that is definable and universal (p. 16).

This focusing on the universal aspect of technology permits us to take a next step in developing content for the study of technology, creating a universal list of technologies that can be applied in the variety of contexts in which humans use technologies and expanding the contexts where people use technology to be more representative of the variety of contexts which exist. The standards document began this process by adding medical, agricultural, related bio, and information to the commonly accepted list of construction, manufacturing, transportation, communication, and energy and power. However, in the standards, contrary to the text of the rationale which preceded them, these are referred to as technologies and not contexts.

"Context" is a much better term and approach than systems for the future in that other contexts that have been ignored in the literature of the field, perhaps, due to the long association with industry, could be addressed. If we are to address agricultural contexts of technology, then, why not the technologies used in the context of the home, business, recreation, and instruction? A universal list of technological processes may very well be representative of the technologies used in a variety of known and yet unknown contexts. Specific knowledge as defined in the rationale could be allied with the context and focus on the nature of technology, the interaction of society and technology, and design for that context.

IV. Design and Inquiry: Bases for an Accommodation Between Science and Technology Education in the Curriculum?

While the connection between science and technology in contemporary times is inescapable, the Hubble telescope or nuclear power plants being dramatic exhibits of this synergy, that relationship has not traditionally played out in the school curriculum. As school subjects, science on one hand, and technology (or technology education) on the other, have had separate existences, the one being well established and bearing high status, the other striving for legitimacy as valid school knowledge, its status often insecure. That unfortunate tradition of separateness in American schools has a real possibility of changing, mainly due to the inclusion of technology as a distinct topic area in published science content standards. In *Benchmarks for Science Literacy*, technology features prominently as science content, with separate chapters being devoted respectively to the nature of technology and the designed world (American Association for the Advancement of Science, 1993). In the *National Science Education Standards*, scientific literacy is said to include one being technologically informed (National Research Council, 1996, p. 22). Science and technology is included as one of the content standards, with 'abilities of technological design" being a primary focus of this standard across grade levels. Technology in the science standards extends well beyond the narrow confines of computers, to encompass the creative endeavors of the human-made world.

As it does in the science standards, *design* features prominently in the technology education content standards (International Technology Education Association, 2000). This new design focus in American technology teaching situates technology education more closely within engineering, making the accommodation with science more feasible. The state of Massachusetts is showing the new prospects for integration by renaming the subject technology/engineering, and by setting forth a joint science and technology/engineering curriculum framework that features a strong emphasis on engineering design (Massachusetts Department of Education, 2001). To focus the teaching of technology towards design is to push the subject away from a content approach toward a process approach—embodied in the methodology of the engineer. Parallel with this process focus within technology education, manifested through design, is a similar focus within science, expressed as *inquiry*, the methodological approach of the scientist. Inquiry is a second pillar of the Massachusetts Science and Technology/Engineering state curriculum. This parallelism between design and inquiry is addressed in the science standards thus:

> As used in the *Standards*, the central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs. *Technology as design is included in the standards as*

> *parallel to science as inquiry* (emphasis added) (National Research Council, 1996, p. 24).

We see a counterpart of this thinking in the technology education standards as well. In the preamble to the chapter on design as a standard, it is reasoned that:

> Design is regarded by many as the core of problem-solving process of technological development. It is as fundamental to technology as inquiry is to science and reading is to language arts (ITEA, 2000, p. 90).

Particularly intriguing is that within the science education community, design is being increasingly viewed as a gateway to student understanding of scientific concepts (see for example Benenson, 2001; Crismond, 2001; Kolodner, 2002). These researchers are blurring the lines between science and technology by using design and inquiry interchangeably as pedagogic approaches, in ways that simultaneously promote both scientific and technological literacy in children. Benenson (2001) argued that systemic reforms in science have come about because of technological demands in the society, and he illustrates how "everyday technology" could be the context for promoting both scientific and technological literacy in children. In similar vein, Crismond (2001) engaged novice and expert designers in *investigate and re-design* tasks finding that the latter group were better able to connect the tasks with scientific principles. Kolodner (2002) uses a "learning by design" approach to teaching scientific concepts. As will be shown later in this paper, her design tasks are quite consistent with the design discourse in technology education.

This section examines the merits of the proposition that design and inquiry are conceptual parallels. It does so by first looking closely at the inquiry-related discourse within science education, then at aspects of the design discourse within engineering and within technology education. Convergences and divergences of these two streams of curricular advocacy are then identified and implications and conclusions with respect to curriculum and instruction in both subjects are suggested.

Advocacy for Inquiry in Science Education

"Science as inquiry" is one of eight categories of content proposed in National Science Education Standards (National Research Council, 1996). Inquiry is operationalized as "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (p.23). It is characterized as

> a multifaceted activity that involves observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations , and predictions; and communicating the results. (p.23).

The underlying logic of this inquiry focus is that science method and content are inextricably related and thus students would better understand and become interested in science if they could enact science by embedding themselves in the actual quest for knowledge.

The current inquiry push has an advocacy tradition that is traceable to the 1960s, in particular to Jerome Bruner's ideas on teaching through discovery. Bruner (1961) viewed inquiry as an intellectual process. Through discovery, which he viewed as "obtaining knowledge for oneself by the use of one's own mind" (p. 22) the learner became more intimately engaged in learning as an active process, and memory was thereby aided. Teaching by discovery required the learner to be a collaborator, and in this mode, he/she was more likely to pursue learning for intrinsic reasons. Bruner described discovery in its essence as "a matter of rearranging or transforming evidence in such a way that one is able to go beyond the evidence so assembled to additional new insights" (p. 22). Discovery was not necessarily dependent on new information. He spoke of discovery as requiring focus on the heuristics of inquiry by which he meant attitudes and activities associated with finding things out. While Bruner's ideas were intended for teaching in general, and not restricted to science, his inquiry heuristics were an important precursor of contemporary advocacy for inquiry science. In its general aspects, Bruner's notion of discovery can be seen to be one of the forerunners of the idea of constructivism in teaching, where learning becomes active and teaching more collaborative.

Where Bruner was advocating discovery as a general method of teaching, others in the 1960s were advocating inquiry not just as process but as the content of science (e.g. Gagné, 1963; Rutherford, 1964; Schwab, 1966). Expressing his support for the idea of inquiry as science content Rutherford (1964) wrote "we stand foursquare for the teaching of the scientific method, critical thinking, the scientific attitude, the problem-solving approach, the discovery method, and…the inquiry method" (p. 81). Science was to be taught as a method or process rather than as content, since "the conclusions of science are closely linked with the inquiry which produced them, and, conversely, that the nature of a given inquiry depends on the topic under investigation" (p. 80).

Rutherford distinguished between *inquiry as content* and *inquiry as technique*. Critical was reference to *scientific* inquiry, not merely teaching students to be inquisitive. Inquiry as technique was consistent with Bruner's discovery learning. Inquiry as content was a special case of Bruner's "heuristics of inquiry" (1961, p. 22). It referred to the intellectual processes that were peculiar to particular fields of science, and crucial in the understanding of the *nature of science*. Inquiry had to include laboratory experience to show students how science actually happened, but laboratory experience of itself was not coterminous with it. Students had to learn about the role of scientific theory in generating new questions and new lines of investigation. They had to learn that a result of inquiry is sometimes to reject theory. This latter version of inquiry was what he advocated.

Schwab (1966) emphasized the importance of thinking in science. His view was that *conceptions* preceded sure knowledge, and were the guiding principles of inquiry. Assuming a constructivist stance, he wrote that the knowledge derived from inquiry is interpreted knowledge. Thus he called attention to the "conceptual principle of enquiry," by which he meant that scientific knowledge was "fragile "and subject to change. Science progresses as new techniques make it possible for new questions and new conceptions to be pursued. Schwab identified two types of inquiry, stable and fluid. Stable inquiry was doctrinal in character, coming to its limits when the scientist was confronted with contradictory data. Fluid inquiry was more speculative, the kind of science that was engaged in invention, and which could take failure in stride. Schwab advocated that laboratories were essential to school science. In the science classroom, an important purpose of inquiry teaching was to help students learn how to ask questions of the materials they study, and how to pursue answers.

Gagne (1963) raised a critical issue with respect to an inquiry approach, by focusing upon its knowledge prerequisites. At what stage in a student's learning of science should inquiry be taught, and upon what conceptual foundation should such learning be premised? Gagne expressed his entreaty thus:

> There is nothing wrong with practicing enquiry, and surely enquiry is the kind of capability we want students of science to attain in some terminal sense. But practicing enquiry too soon, and without a suitable background of knowledge, can have a narrowing and cramping effect on the individual's development of independent thinking. (p. 147)

He was of the view that inquiry was a critical intellectual capability to accrue from engagement with science, but that there were two other equally important and complementary capabilities, namely the ability to generalize the principles to a variety of situations and ability to evaluate the applicability of hypotheses to new problem situations. Generalizeable knowledge gave students a storehouse of principles upon which they could draw as they posed new problems.

Out of these early contributions to advocacy for the teaching of inquiry one could glean some foundational ideas that persist in contemporary times. Among these include (a) that scientific knowledge is inextricably bound up with the methods of scientists, (b) that the knowledge yielded by science is changeable over time, and (c) that there is a difference between inquiry as a process of learning science, and inquiry as science content. Though there has been general agreement over time that the methodology of the scientist provides clues to scientific knowledge, just what constitutes the scientific method is not a settled question.

The Scientific Method as a Contested Idea

Kneller (1997) writes that while there is no single scientific method, all investigations involving a hypothesis have in common a set of activities that are very similar to the structure of everyday problem solving. This sequence includes "problem, hypothesis, inference, test, feedback, change of hypothesis, and the sequence repeated" (p. 13). As example, Kneller sets forth a hypothetical scenario in which a researcher observes a fact that is at odds with established theory. This disagreement is framed as a problem. Upon investigation, the researcher proposes a solution in the form of a hypothesis that becomes the basis of deductions as to likely results if it is correct. Data are collected and are compared with the predictions. If the data and predictions are in agreement, then, the hypothesis is confirmed. If not, then the researcher has a range of options including proposing another hypothesis. Kneller goes on to point out that this approach describes some but not all scientific inquiry. He identifies classes of scientific research in which this method is not applied since hypotheses are not invented. They include *consolidation* (validation of a stated theory); *extension* (application of a law or theory to new areas); *reformulation* (simplification of a theory to make it more applicable); and *theory construction* (creation of new laws or theory).

Distinguishing between teaching science *as* inquiry rather than *by* inquiry Chiappetta (1997) offers a view that is somewhat in keeping with the method suggested by Kneller. The emphasis is on active learning, and inquiry involves (a) questions, (b) science process skills, (c) discrepant events, (d) inductive activities, (e) deductive activities, (f) gathering information, and (g) problem solving. Questions involve students posing problems of personal interest. Process skills focus on the knowledge construction approach of scientists including stating problems, forming hypotheses, constructing inferences, conducting experiments, and communicating findings. Discrepant events stimulate students to engage in reasoning in their quest to unravel puzzles. Deductive activities present students with empirical data that become the basis of theorizing. By contrast, inductive reasoning encourages students to offer conceptualizations prior to empirical testing. Information gathering is threaded through all stages of the learning cycle.

Edwards (1997) contended that published materials tend to be too structured to help students engage in inquiry. Bona fide inquiry required that students "formulate their own questions, create hypotheses, and design investigations that test the hypotheses and answer the questions proposed" (p. 18). Students' question-asking ability could be aided with the provision of observable phenomena as stimuli, or by having them read articles relating to current scientific events. Their investigative ability could be enhanced if they design experiments that test hypotheses, find confounding variables, make decisions, and draw conclusions. Edwards was of the view that for inquiry to occur, it had to be properly conceptualized. Traditional laboratory materials had to be replaced by inquiry-based, student-initiated investigations.

Reporting on actual classroom experience with teaching science as inquiry, Thompson and Hellack (1986) agreed that forming and testing hypotheses is the core activity of science, and that such aspects of inquiry are crucial for beginning students. In a fruit-fly experiment, they adopted the following model of inquiry: (a) make observations, (b) form hypotheses, (c) test hypotheses and evaluate them, (d) make predictions, and (e) test the predictions to see the generality of the hypothesis. In practice, students (a) summarized observations of fruit flies as they reacted to various stimuli (light, gravity, tube rotation and tapping on tube, (b) proposed hypotheses explaining the orientation of the flies as they reacted to the different stimuli, and (c) tested these hypotheses. Puzzles posed by this experiment included whether the flies were responding to light (phototaxis) or to gravity (geotaxis). The authors explained that the experiment offered many opportunities for hypothesis formation and testing, commenting that "Good science often generates more questions than answers" (p. 25).

The idea of a scientific method ignores the actuality of science which is one where human frailty has to be contended with as in other spheres of life. The notion of scientific knowledge as objective knowledge can be contested, given that such knowledge may be conditioned by predispositions of the scientist. Scientists may be blinded by the strong belief they have in the hypotheses they have proposed. Or, they could be led down the wrong path by faulty theory. Driver, Asoko, Leach, Mortimer and Scott (1994) argue that "scientific knowledge is both symbolic in nature and also socially negotiated. The objects of science are not the phenomena of nature but constructs that are advanced by the scientific community to interpret nature" (p. 5). They point to the qualitative component of scientific knowledge, as evidenced in the symbol world of science, where concepts such as atoms or genes, are "unlikely to be discovered through their own observations of the natural world...(rather) Scientific knowledge is constructed and communicated through the culture and social institutions of science" (p. 6). The understandings that accrue from scientific endeavor, the meaning making that is so fundamental to inquiry, are crystallized when individuals engage socially in communities of practice, talking and sharing problems.

Kuhn (1970) raised doubt about the notion of scientific inquiry as a step-wise process, contending that the acceptance of new scientific knowledge turns on whether the scientific community is ready to reject a held paradigm—(a particular way of thinking about particular phenomena). Scientific revolutions, the replacement of one mode of thought with another, have a cultural and historical component. When scientists are confronted with discrepant events, they invariably do not renounce the theory—the paradigm- that led them to the anomaly. If data do not square with predictions, they do not, as the standard model of scientific inquiry suggests, automatically conclude that they are on the wrong track. According to Kuhn, "No process yet disclosed by the historical study of scientific development at all resembles the methodological stereotype of falsification by direct comparison with nature" (p. 77). What leads scientists to reject held theory is not falsification of such theory through observation of nature, but rather "simultaneously the decision to accept another" (p. 77). Kuhn's characterization of the ethos of conformity that characterizes scientific culture, suggests that pure rationality does not fully dictate the acceptance of new knowledge, even where such knowledge is yielded by the accepted method of inquiry.

The strong influence of scientific culture on knowledge production has effect also on the rejection of findings validly arrived at, where such findings are not yielded by prevailing conventional wisdom. Bauer (1992) cites several instances in scientific history where findings were ahead of their time, and not accepted. In a chapter titled "The So-called Scientific Method" Bauer, like Kuhn, contests the standard model of scientific inquiry. He offers a range of arguments and illustrations suggestive of the need for reserve in reading undue rationality into the process of scientific inquiry. Bauer argues that in the field of chemistry there are many “tribes” each of whom approaches inquiry in its own peculiar way. He further points to instances where the calculations of scientists were different from experimental values, and where the right decision was to trust the calculations. Drawing on the race to invention of DNA, he shows how Watson and Crick made allowances for experimental error in their data. He writes: “Evidently, then, some of the most successful chemists have not practiced the proper scientific method, which is supposed to put evidence first and theorizing second” (p. 23). But scientists have sometimes also placed too much faith in theory, notes Bauer, standing by theory in the face of evidence to the contrary. Or, he cites instances where theory has so blinded scientists as to cause them to see results that do not exist. Thus, contends Bauer, the nature of science and the scientific method is misconceived. Geologists, biologists, physicists, and chemists do not follow the same inquiry logic. There is variation among them including the way in which they use mathematics. Some sciences might be observational and others experimental, with the former at the mercy of nature. Some scientific disciplines (such as chemistry or geology) are data driven while others (such as astronomy) are theory driven. Some are quantitative and others qualitative. These differences among sciences yield differences in attitude *and method*. Bauer contends then:

> That the scientific method is a myth, that it does not explain the success of science and that scientists in practice do not follow the method, does not mean that the method itself should be disparaged. Rather, it should be seen as an ideal—an admittedly unattainable ideal—not as a description of actual practice. (p. 39)

Inquiry Research

One strand of inquiry-based research in science education has focused upon in situ observation of inquiry teaching and learning (Polman & Pea, 2001; Toth, Suthers, & Lesgold, 2002). A second thrust has been aimed at discerning the inquiry dispositions of pre-service (Crawford, 1999; Tamir, 1983; Windschitl, 2002), and in-service (Lederman, 1999; Weinburgh, 2003) teachers.

Polman and Pea (2001) illustrated through accounts of classroom episodes, how *transformative communication* was utilized in a science classroom premised upon open-ended science inquiry, in a way that allowed for expression of the voices of both teacher and student. Transformative communication fosters social interaction that creates meanings shared and contributed by both. The researchers identified a common pattern of dialogue between students and teacher as the former engaged in inquiry. The sequence included:

> 1. Students make a move in the research process with certain intentions, guided, as well as, limited by their current knowledge.
> 2. The teacher does not expect the students’ move, given a sense of their competencies, but understands how the move, if pursued, can have additional implications in the research process that the students may not have intended.

> 3. The teacher reinterprets the student move, and together students and teacher reach mutual insights about student's research project through questions, suggestions, and/or reference to artifacts.
> 4. The meaning of the original action is transformed, and learning takes place in the students' zone of proximal development, as the teachers' interpretation and reappraisal (i.e., appropriation) of students' move is taken up by the student. (p.227)

One episode illustrated students who, having explored the topic dinosaurs, focused upon plesiosaur. Having decided on this species, they proposed a research question, namely "Are accumulations of plesiosaurs associated with areas of high marine productivity" (p. 229)? A second episode involved a UFO group engaged in confirming/disconfirming research. A third involved a hurricane group analyzing data obtained from a scientist with whom they had been placed in contact by their teacher. The researchers concluded that the teacher's quest to involve students in research design, and in the selection of analysis techniques, was superior to a more traditional approach to science teaching.

Toth, Suther, and Lesgold (2002) examined the effectiveness of translating web-based information into two forms of representation, namely evidence maps and prose. The subjects were ninth grade science students. The researchers first conducted in-service professional development for the teachers, emphasizing student-centered, collaborative learning. The classroom approach was to work collaboratively with teachers, placing students in teams to work on problem-solving challenges. The authors found positive results for the effects of representational guidance using evidence mapping, and explicit reflection.

Tamir (1983) examined whether there were differences in the conceptions of inquiry held by pre-service teachers, compared to practicing teachers. The study found that experienced teachers were more inclined than pre-service teachers to associate inquiry with scientific research. Experienced teachers were also more aware of the nature of science as inquiry. Neither type of teacher viewed inquiry in terms of some of its foundational premises. The author noted:

> It is interesting to note that certain cornerstones of science as inquiry, such as the history of scientific ideas, the tentativeness of scientific knowledge, doubts, conflicts, personalities, and personal experiences of scientists are mentioned neither as associations nor as parts of definitions. The image of science as inquiry which emerges is, by and large, that of systematic step by step process based on observations and experiments which give results that are to be interpreted and which lead to conclusions and scientific laws. There is no mention of the fluid nature of science…. (p. 661)

Crawford (1999) questioned whether novice teachers could successfully construct an inquiry-based environment for science learning, especially where inquiry is interpreted as teaching to help students pose and answer important questions, employing techniques similar to that of scientists. The researcher studied a pre-service student teacher in action, guiding students as they conducted experiments examining the nitrogen content of manure. It appeared that novice teachers can in fact acquire competence in inquiry-teaching, one limiting factor being their held beliefs about the nature of inquiry. Whether teachers' understanding of the nature of science affected classroom practice, and what were the factors that impeded the effects of such understandings on practice, were questions guiding the work of Lederman (1999). The findings were consistent with the view that scientific knowledge is tentative, premised upon human creativity and imagination—that it was essentially subjective, being theory laden, though based on empirical evidence. Teachers also understood the difference between observation and inference. However, their conceptions did not appear to influence their practice.

Weinburgh (2003) contended that middle school science teachers may not have an understanding of how science is conducted in real world environments. Subjects in this study were in-service middle school teachers. They interviewed scientists in situ, generally finding that none worked in a linear way--rather their approach could be characterized more as circular. Results showed that though these teachers began the term thinking that the scientific method was linear, and well defined, they showed change in thinking after their exposure to practicing scientists during the study.

Windschitl (2002) investigated how the inquiry experience of pre-service teachers in a science methods course influenced their thinking about classroom practice. The teachers maintained journals reflecting on their inquiry journeys. They wrote descriptions of the relationship between the phases of inquiry, and created metaphors for inquiry. Findings were that the participants who had the more authentic views of inquiry after the in-service experience were those who had prior science research project experience in their undergraduate coursework.

Design

As indicated above, design features prominently in the American standards for teaching technology (International Technology Education Association, 2000). This section of the paper explores design as it is employed by engineers as their primary means of solving problems. Design is also part of the craft tradition, but it is engineering, not craft, that inspires the standards for teaching technology. How design is viewed within the subject, including research evidence, is also explored.

Design in Engineering. As with inquiry, there is a degree of consensus within engineering on the outlines of a general design methodology. A typical conception is that offered by French (1999), in which the design process is shown to be iterative rather than linear, and comprised of (a) a need, (b) problem analysis, (c) statement of the problem, (d) conceptual design, (e) selected schemes, (f) embodiment of schemes, (g) detailing of solution, and (h) working drawings (p. 2). The designer can backtrack at any time along the way to a solution. Conceptual design is the heart of the process. French writes that it is "the phase that makes the greatest demands on the designer, and where there is the most scope for striking improvements. It is the phase where engineering science, practical knowledge, production methods, and commercial aspects need to be brought together, and where the most important decisions are made" (p. 3).

Conceptual design features as a significant stage in "systematic design" as set forth by Pahl and Beitz (1995). These authors divide the design process into four main stages, namely (a) product planning and task clarification, (b) conceptual design, (c) embodiment design, and (d) detail design. The trigger is customer need. They characterize conceptual design thus:

> Conceptual design is that part of the design process in which, by the identification of the essential problems through abstraction, by the establishment of function structures and by the search for appropriate working principles and their combination, the basic solution path is laid down through the elaboration of a solution principle. Conceptual design determines the principle of a solution. (p. 139)

They note that this aspect of design includes an abstraction phase intended to push the designer away from fixation and conventional solutions. The designer focuses on the general and essential rather than the particular or incidental. He/she determines function structures, which are decomposed into sub-functions. Working principles are developed for sub-functions, and these are combined into a *working structure*. When made concrete, the working structure leads to the solution principle. This stage of design involves theoretical ideas along with the physical process, and geometric and material characteristics . It leads to several solution possibilities called a "solution field." These solution variants have to be evaluated. They lead to the concept of technical product.

Kroll, Condoor and Jansson (2001) divide the engineering design process into three phases—need identification, conceptual design, and realization. Need identification is concerned with functions and constraints. Function is the main purpose of the design. It could be broken into sub-functions. Constraints are boundaries or limits on the solution space in which the designer searches, as he/she seeks to head-off downstream design issues. Five types of functions/constraints are identified, namely performance, value, size, safety, and special. The designer studies tradeoffs, such as value versus performance. The process for considering functions and constraints is not sequential. The designer may back track if need be. These authors contend that conceptual design is more difficult than other stages of design. It involves discovery. They propose *parameter analysis* as the "systematic method" for conceptual design. Parameter analysis is comprised of three activities (a) parameter identification…recognition of issues of the problem, (b) creative synthesis… generation of "physical configurations," and (c) evaluation. They offer the following as characteristics of parameter analysis:

- Behind every configurational attribute of a design there must be a conceptual reason for 'justification'
- Developing a design requires focusing on one or very few conceptual issues at a time
- The most creative aspect of conceptual design is not the invention of a new configuration, but rather the designers' ability to discover a conceptually new way of looking at the problem

- The key to good conceptual design is a thorough understanding of the underlying physics of design artifacts
- Conceptual design is not pure synthesis; rather, it consists of a partnership between synthesis and analysis
- Good design is a synthesis of a series of good ideas, or concepts, not just one good idea. The parameter analysis methodology helps to create ideas and incorporate them into a single design. (p. 69)

Design parameters may include the dominant science governing the problem, new insight into critical relationships, or an analogy. Parameter identification includes *simplification* of the problem by stripping it of less important features, use of simple models, and focusing upon make or break issues. It also involves *transformation*—such as rephrasing the task, or stepping back and thinking analogically.

Koen (1985) proposed the “engineering method” by which he meant “the strategy for causing the best change in a poorly understood or uncertain situation within available resources” (p. 5). According to Koen the engineer relies upon heuristics to guide design. These heuristics do not guarantee a solution, but they can aid in the solution of problems that would be unsolvable using conventional analytic techniques. Heuristics reduce the search time in solving a problem. In Koen’s view, much of the engineer’s work is under the control of heuristics. He identified five categories of heuristics:

> 1. Some rules of thumb and orders of magnitude
> 2. Some factors of safety
> 3. Some heuristics that determine the engineer’s attitude toward his work
> 4. Some heuristics that engineers use to keep risk within acceptable bounds
> 5. Some rules of thumb that are important in resource allocation (p. 45) . . . For a mechanical engineer, one rule of thumb is that a bolt should have one and a half turns in the threads. For a chemical engineer making a heat transfer calculation, a valuable heuristic is that air has an ambient temperature of 20 degree centigrade and a 80-20 mixture of nitrogen and oxygen. (p. 47)

A challenge for the designer who has come to the end of the conceptual design stage is how to evaluate the possible solutions. For this Suh (1990) has offered *axiomatic design.* Suh writes that design consists of two distinct processes, a creative process in which new ideas are synthesized, and an analytic process in which proposed ideas must be evaluated. The creative process “depends strongly on the designer’s knowledge base and creativity, and is subjective” (p. 9). This process can yield an infinite number of solutions. By contrast, the analytic process is deterministic. The two processes are inter-related, and axiomatic design is a way to formalize the relationship between them. Suh proposed two design axioms:

> Axiom 1: The Independence axiom. Maintain the independence of functional requirements . . .

Axiom 2: The information axiom. Minimize the information content. (p. 72)

The first axiom separates feasible from infeasible design, while the second selects the optimum design solution from among those deemed feasible. Together these axioms impose constraints on the design. According to Suh, a challenge for design has been to arrive at a methodology that can aid in the evaluation of options. For example, one sees a rudimentary evaluative methodology offered by Hubka (1982) comprised of a rubric through which points are assigned based on suitability. Morphological evaluative techniques have been set forth such as in Pahl and Beitz, (1995) and Hubka, (1982) in which a matrix that juxtaposes the various functional requirements against all design options. Suh points out that such evaluative processes fall short of offering rational design solutions, and that axioms help to streamline what otherwise are hit and miss processes. Axiomatic design requires that functional requirements of the design along with design parameters, be identified and decomposed into hierarchies. The designer must be able to switch from functional to physical domains. Parameters include input constraints (e.g. constraints on design specifications such as size, weight, and materials cost) and system constraints (e.g. geometric shape, machine capacity, and natural laws). Matrix algebra is utilized in arriving at the optimal design.

In an illustration of axiomatic design, Sekimoto and Ukai (1994) describe their basic design approach as including four steps: definition of functional requirements, ideation, analysis of proposed solutions to choose the best solution, and checking the final solution. Each step involves iteration that may require redefinition of functional requirements, arriving at new ideas, or modifying proposed solution. The designer first sets forth functional requirements for the product, then begins development of its physical embodiment. Functional requirements are mapped onto design parameters in a design matrix. Such a matrix can be constructed for each possible solution. The independence and information axioms are used to arrive at the design.

Design in Technology Education. Design had been an established feature of technology education in the United Kingdom before it took hold in the American version of the subject. As Wright (1993) pointed out, design was added to the craft design technology (CDT) phase of the subject in the United Kingdom after 1975, designing/making being a critical curriculum nexus. Design features prominently in the version of the subject, design and technology, that was included in the United Kingdom's National Curriculum. Four design and technology "attainment targets" make up the core of that curriculum (Department for Education, 1990). The first target focuses upon need identification and opportunities. Students are expected to identify design opportunities in contexts such as home, school, and community. The second target is "generating a design". It requires students to "generate a design specification, explore ideas to produce a design proposal and develop it into a realistic, appropriate and achievable design" (p. 7). Of interest here is that the motif of the design and technology curriculum in the United Kingdom's national curriculum, is a generic design process—finding a need, generating the design, planning and making (the design embodiment), and evaluating design efforts. Design in the British curriculum, as characterized above, has strong craft origins, though the basic design framework is partial both to craft as well as engineering traditions, and, indeed, allows for context-independent problem-solving in everyday situations and contexts that range far from engineering.

Commenting on the teaching of design in the British curriculum, McCormick and Davidson (1996) cautioned that teachers were giving precedence to products over process. Wilson and Harris (2003) examined best practices in teaching and learning of design and technology in England and Wales, finding some support for the teaching of procedural skills and general support for the teaching of intellectual skills. But one does not see in this comprehensive review of design practice in the schools any special focus on the design methodology as technological content. Other observers of the teaching of design in British schools cautioned that teachers were pursuing a simplistic line when doing so, following a design model comprised of stages that was often contrary to the natural design tendencies of children (e.g. Chidgey, 1994; Johnsey, 1997) Proposing alternatives to design as pedagogy for technology education, Mawson (2003) acknowledged that design as a process had become a standard approach to the teaching of the subject in England, Australia, and new-Zealand, with *design-make-appraise* being the common motif.

Design has within recent years become a more explicit provision of the American version of technology education, emerging after a period in the 1980s and 1990s in which the focus had been on a content or discipline-based approach to curriculum. Savage and Sterry (1990) proposed the technological method as an essential aspect of a framework for teaching technology. In a vein similar to design and technology in the British National Curriculum, the basic motif of design was a sequence of steps inclusive of (a) problems and opportunities springing from human needs and wants (b) technological processes, namely analyzing, realizing and testing, (c) evaluation, and (d) solutions and impacts. Drawing upon cognitive science research, Johnson (1992) proposed an intellectual processes approach to teaching technology, with focus on meta-cognition and creative problem solving skills. He called particular attention to the consonance between the intellectual processes approach he was advocating and technological problem solving as follows:

> Because technology education content is often taught through a problem solving method…technology teachers need to act like technologists in their classrooms. They need to solve unfamiliar technological problems for students and not be afraid to make errors or have difficulties finding solutions. By serving as a role model, technology teachers can show students how to collect and use information to solve technological problems and help them realize that not all problems have straight forward and simple solutions. (p. 34)

This process approach has become the status quo in American curriculum thinking, embodied in design with its problem-solving concomitant. As indicated above, design stands at the core of the *Standards for Technological Literacy* (ITEA, 2000). More importantly, these standards have the explicit imprimatur of the American engineering establishment, as can be seen in the commemorative foreword of the standards, written by the President of the National Academy of Engineering. The standards make clear that the design logic of the curriculum is premised on the work of engineers, not artisans. How engineers approach design is set forth as follows:

> The development of a technology begins as a desire to meet a need or want. These needs or wants could belong to a single inventor or be shared by millions of people. Once needs or wants have been identified, the designer must determine how to satisfy or solve them. The modern engineering profession has a number of well developed methods for discovering such solutions, all of which share common traits. First, the designers set out to meet certain design criteria, in essence, what the design is supposed to do. Second, the designers must work under certain constraints, such as time, money, and resources. Finally the procedures or steps of the design process are iterative and can be performed in different sequences, depending upon the details of the design problem. (p. 90)

As indicated above, the state of Massachusetts has been a leader in embracing the engineering design bent of the standards. The state curriculum guide anchors this content via an eight-step generic design process as follows: identify the need or problem, research the need or problem, develop possible solution(s), select the best possible solution(s), construct a prototype, test and evaluate the solution(s), communicate the solution(s), redesign. (Massachusetts Department of Education, 2001, p. 73)
This process is fitted onto a design wheel, not unlike that suggested in Hutchinson (2002).

How design is situated in the technology education curriculum can be gleaned from published accounts focusing sometimes on children, and at other times, on teachers. Such accounts can be seen in the American as well as broader international literature. Two noteworthy pedagogical approaches that feature a design process intending to teach scientific content are offered by Zubrowski (2002) and Kolodner (2002). Zubrowski proposed a pedagogical model that would integrate scientific content into the process of children learning technological design. The model is comprised of three phases. In the first there is exploration, in which students brainstorm ideas about building a functional artifact. The second stage involves them putting aside preliminary constructions and considering a standard model that is a synthesis of class ideas. Students conduct systematic tests, controlled experiments, at this stage. In the third phase, they go back to an open design process in which they can incorporate ideas they have gained in considering the standard model, or they can arrive at a completely new design. Zubrowski recounted how this process worked, in a class where students were challenged to attach a cup and string to the rotating arm of a windmill to allow it to lift weights. Students engaged in the trial and error phase, then worked on a standard model to the point where essential features of a functional windmill were yielded. They then went back to designing on their own, improving their individual designs as they saw fit.

In an interesting approach that she coins *learning by design* (LBD) Kolodner (2002) examined how the design process in technology and science learning can be mutually reinforcing. She reports results showing that LBD students outperform non-LBD peers in ability to design experiments, planning for data gathering and collaboration. Students learn science by engaging in technological design. Five principles underlie the work, namely; foregrounding of skills, practicing, establishing need, making recognition of applicability automatic, and establishing and reinforcing expectations (p. 31). Kolodner asserts that "Construction and trial of real devices gives students the opportunity to experience uses of science and to test their conceptions and discover the bugs and holes in their knowledge" (p. 18). Her process includes two learning cycles (a) a *design/redesign* cycle, in which students *mess about* and (b) an *investigate and explore stage*. In a challenge requiring students to build a propulsion system from balloons and straw that could cause a coaster car to go as far as possible on flat ground, students first messed about in a white-boarding exercise, identifying ideas. They then gathered together to share observations. Next they entered the investigate and explore stage in which they made predictions about the performance of the designs. Here they ran experiments and gathered data. They also spent time learning about Newton's Third Law, on equal and opposite forces, science content they needed to help explain the behavior of the car. From this they returned to the design planning phase to deal with the constraints and criteria of the design challenge. They then built and tested cars, using scientific content knowledge to predict the performance of their design. Kolodner indicates that a critical aspect of her LBD approach is having students learn to reflect upon and refine their reasoning ability. Sharing and refining ideas publicly with peers is a key feature of the approach.

Some studies have focused on design from the perspective of pre-service teachers of technology. Parkinson (2001) examined pre-service teachers understanding of structures. They had to design and make a structure that would span a gap so it could be traversed by a simple vehicle. Materials were paper clips and sheets of paper. The students seemed to have incomplete understanding of how a structure can push back against a force. Another misconception was that was that paper was not strong. Parkinson suggested that this task was an example of how science and technology could be mutually reinforcing. McRobbie, Stein and Ginns (2001) examined pre-service teachers as novice designers, mapping their reasoning process. They found a lack of fit between generic step-by-step models and how the teachers actually approached the design tasks. Important to the teachers was the use of three-dimensional modeling. Rather than trial and error, their actions seemed to be based upon predictions and logical conclusions, comprised of 'reasoned generate-and-test procedures" (p. 109). The reasoning approach employed by the teachers followed a 'see-move-see again" process (p. 109). The authors found the design process for these teachers/novice designers to involve the interplay of tools, materials ideas and people.

Some studies have focused upon elementary teachers negotiating the design process. Rogers and Wallace (2000) found that elementary children confused the difference between drawing a picture and making a design drawing, and that they did not see the connection between their designs and making. These authors suggested that special approaches to teaching design might be necessary for the elementary grades. Welch (1999) studied grade 7 students who were unschooled in any design process as they engaged design tasks. The students were given a sheet of paper and the task was to construct the tallest possible building that could stand for 30 seconds. Codes were developed to map the reasoning process of students. The researchers found that the strategies students used were complex and not linear. They included using serial strategies, trying out, then, abandoning solutions and moving on to the next solution. Modeling in three-dimensional materials was an important aspect of their solution process, featuring in their understanding of the problem, generating solutions, and testing and improving solutions. The importance of this study is that, like McRobbie, Stein and Ginns (2001) the study contests the idea of a step-wise problem solving approach to design. Left to their own devices, students would tend toward solution strategies that deviate markedly from the generic design script.

Design and Inquiry: Convergences and Divergences

The discussion this far has examined how the processes of inquiry and design are perceived respectively in the scientific and engineering communities, and how they are reflected in the school curriculum through school science where inquiry is concerned and technology education where design is concerned. The question to be addressed next is just how much are these two processes conceptually similar, and in what ways are they not.

Convergences. Design and inquiry are fundamentally reasoning processes, ways in which engineers on one hand and scientists on the other, come to terms with puzzles that confront them. They are navigational devices that serve the purpose of bridging the gap between problem and solution. In both cases, the path from problem to solution may require back-tracking, including re-statement of the problem, as the engineer or scientist comes to dead ends, or as they are able to rule out the likelihood that a particular pathway can be fruitful. Accordingly, both design and inquiry conform to Newell and Simon's (1972) insights regarding the nature of a solver's search through a problem space, during which there is expansion of knowledge of the problem situation, until a solution is arrived at. Both the engineer and scientist must re-evaluate their representation of the problem that occupies them, as they move toward solution, and in the process of so doing, both would find working memory to be limiting and instead come to rely upon a variety of schemata (Hunt, 1994).

While some design and inquiry problems are in the realm of the routine, at the more challenging end of the spectrum both types tend toward being ill-structured and characterized by uncertainty. *Uncertainty as a starting reasoning condition* is indeed a common signature of both processes, one that requires in both cases the systematic ruling out of extraneous variables. Uncertainty as a common contextual condition also makes both design and inquiry fundamentally creative processes that demand expenditure of cognitive resources in the form of search strategies.

As they engage in search, both engineer and scientist must rely upon like cognitive reasoning tools, such as *brain storming or analogical reasoning* during the search stage (e.g. Hallyn, 2000; Koen 1985). At the conceptual design stage, the engineer finds that the search process is aided greatly by postponing engagement with the physical realm and resorting to abstraction. Here the quest is for the principle of the design. This is akin to the role that theory plays in scientific inquiry. Theory helps the scientist to narrow the pathways to solution. Through hypotheses informed by theory, the scientist avoids mere random search, and instead engages in more purposeful quest.

Both engineers and scientists resort to mental models and often *visual representation* of their ideas as a means both of rehearsing and communicating thought. The scientist may utilize graphics to work out chemical structure. The engineer may use graphics in the form of line drawings or sketches to illustrate the workings of a particular design—testing whether components fit together. Beyond graphics, it is often necessary in design as in inquiry to create three-dimensional models of solutions that aid greatly in the reasoning process. Such models played a vital role in Watson and Crick's final push to discovery of the structure of the genetic code. Engineers can use mock-ups to provide insight that can then be transferred to the construction of prototypes.

In the late stages of search in both design and inquiry, there is need for *testing*, evaluation and decision-making. In design, the issue is which of a narrow set of solution alternatives best conforms to design parameters, while for inquiry, the question is how do the empirical data compare to hypothesized results. Beyond the conceptual similarity that attends the evaluation stages of design and inquiry, is the fact that for both processes this stage bears co-equal critical weight. Which of a set of design options should be moved to the embodiment stage, and how far away are a set of experimental results from theory, are extremely important and challenging cognitive tasks, better accomplished by experts than by novices.

While inquiry and design are often reduced to generic procedures, and are taught as content in their own right, it seems clear from the respective literatures as set forth above that in practice both these processes depend upon *content knowledge*. Confronted with a challenging design problem, the engineer must draw upon a base of knowledge that might include requisite physics or mathematics, materials, techniques, engineering codes and standards, an array of design heuristics, patent histories, components, and the state of the art. A knowledge base of this order becomes part of the raw material of creative thought. Like the engineer, the scientist engaged in inquiry does so by drawing upon a reservoir of knowledge. In the *Double Helix*, in which Watson (1968) describes the quest for understanding of the genetic code, he and colleagues brought to bear a store of foundational scientific knowledge from a variety of fields, including genetics, biology, chemistry, and physics. Gagne (1963) made clear that scientific conceptual knowledge must be the foundation of inquiry.

The work of engineers and scientists converge on an operational level, in their approach to resolution of day-to-day questions, on their way to answering or asking bigger questions that could advance their work. They must both engage in forms of trial, error and reflection, learning from failure, and making adjustments in their hypotheses and in their lines of approach. In their resolution of the small, day-to-day questions, inquiry and design look alike, bearing resemblances that make them conceptually and practically indistinguishable.

Finally, engineering design and scientific inquiry have in common that they are both constrained by paradigmatic thinking. Kuhn's (1970) observations regarding the cultural and historical dimensions of change in science have been discussed earlier. In similar manner, basing his observations on case studies of engineering error through history, Petroski (1994) has shown that change in engineering often comes through failure caused by human error, such error often lying latent within what appears to be engineering success, waiting for the right set of events for failure to reveal itself. For example, the error might lie in the accepted design approach to one structural aspect of the approach to bridge design. Only with failure comes wholesale re-evaluation of extant practice. Petroski cites as example the impact of the Challenger disaster in 1986 on the approach to the design of spacecraft, and on the management of their launching.

Divergences. While design and inquiry converge on many dimensions, as indicated above, these processes also diverge. A few important areas in which they do include purpose, role of constraints, role of trade-offs, role of failure, role of context, and practicality tests.

<u>Purpose</u>**.** A major area of divergence between design and inquiry is in their purposes. Scientific inquiry has pure and applied dimensions. Applied science is instrumentally inspired, as in the search for cures for diseases, or the development of resistant varieties of food crops. Pure science is inherently speculative, fueled more by curiosity—by the pure desire to try to unravel secrets of nature. In this vein, such scientists are interested in the behavior of some materials under cryogenic conditions. Others are interested in probing the geologic record of Mars, to understand better how that planet evolved, such knowledge in turn illuminating our understanding of how earth might evolve. Unlike scientific inquiry, design does not have a purely speculative component. The purpose is always instrumental—inventing an artificial heart, minimizing structural failure in an earthquake zone, or constructing a tunnel that improves the movement of people.

Because of divergence of purpose, the questions that are the starting point of scientific inquiry must be of different character from those prompting design. The engineering design challenge posed by the Hubble telescope was how to get it to provide as clear a view as possible back in time. Scientists using the Hubble for inquiry are interested in large fundamental questions relating to origins of the universe. Where in scientific inquiry one speculates on grand questions such as how the universe evolved, or the extent of global atmospheric warming, engineering design deals with questions that are more grounded, such as why did a particular bridge fail.

Constraints. Fundamental to the process of design is the limiting factor of design constraints. Constraints for a particular design might include time, costs, laws, building codes, or aesthetics. Constraints impose restrictions on the designer, by suggesting practical boundaries within which the search for solution must occur. These restrictions are in fact invitations to creativity. The essence of design is embodied in the ability of designers to overcome imposed restrictions through creative solutions. Automobiles of today must meet exhaust-emission, fuel-efficiency, and safety standards, among others. Constraints of this order tax the creativity of engineers, who, in addition to working within them must also try to keep costs down for the consumer. Scientific inquiry must take into account the limiting constraint of cost, but cost considerations are not as intrinsically woven into scientific reasoning, as it is into design reasoning. Once the decision to pursue scientific inquiry is made, the work does not proceed with *a priori* limiting constraints as does design. To the contrary, inquiry emanates from the nature of the problem requiring resolution. The scientific problem has to be kept open, lest important clues for solution are missed.

Trade-offs. In the course of design reasoning, engineers must make trade-offs. To design a car that can protect drivers better in collisions will require consideration of trade-offs between costs and safety. Some designs might require trade-offs between aesthetics and functionality. The completed designed product or system embodies a regime of trade-offs. Contrarily, scientific inquiry has no real parallel to this form of reasoning, allowing for the fact that decision whether to start or continue a scientific project could be based upon an estimation of the opportunity costs associated with the project.

Failure. As indicated earlier, both scientists and engineers must contend with failure on their respective journeys through the problem space in search of solution. Failure helps both to understand their problem better and to make adjustments in their line of attack. But beyond this commonality, failure has a place in design reasoning that extends beyond that which is shared with inquiry. Poor design can lead to collapse of structures, such as the buckling of bridges under load, the breaking of dams, or to the malfunctioning of equipment. A pacemaker intended to stimulate the heart into rhythmic functioning must work every time. An ATM machine must pay out only that cash which is requested. Reflecting upon the design of everyday commonplaces such as the aluminum soda can, Petroski (1994) writes that "The concept of failure is central to the design process, and it is by thinking in terms of obviating failure that successful designs are achieved. It has long been practically a truism among practicing engineers that we learn much more from failures than from successes" (p. 1). According to Petroski, it is when engineers fail to tacitly factor failure analysis into their design conceptions that actual failure occurs. Failure considerations, therefore, rise to the level of a design principle. There is equivalent to this manner of reasoning within scientific inquiry.

Context. Engineering problems are shaped by the strictures imposed by context. The design of heart pace-makers must take into account the environment of the human body within which they would have to be lodged. Tall structures in earthquake zones must be constructed more dynamically than structures outside of such zones. This sensitivity to particular contexts is not a feature of scientific inquiry. To the contrary, scientific solutions are transcending—they seek generalizable contexts.

Practicality Tests. Beyond the critical question "does it work?" lie other practicality criteria for designs including whether the design can be manufactured, or whether component parts can be assembled. A very functional component design on paper on in simulation might not be suited for pouring in the foundry. These commercial considerations must be included in the reasoning process of engineers when they design products. Failure to take them into account could be quite costly. Hence "design for manufacturability" has become a limiting condition on design engineers. Such practicality criteria do not have parallels in scientific inquiry. It is true that scientific processes first honed in laboratories are frequently scaled up for commercial purposes, but by then scientific inquiry merges into engineering. For example, the production of ammonia on a large scale is as much an engineering design problem as it is scientific inquiry.

Conclusion

The discussion above began by reflecting upon new possibilities for unity of science and technology in school curricula, drawing upon the fact that such unity represents the status quo in society. Science and technology are sides of the same coin. The typical lack of collaboration of these subjects in the curriculum does not authentically reflect contemporary progress. Old rigidities, engendered by the view that technology, the school subject, was no more than craft might have been a reason for the reluctance for curricular accommodation. But that is changing in the United States, with both the scientific and engineering communities recognizing that they have a stake in children becoming technologically literate (e.g. Pearson, 2002), and both calling for the nature of technology and an understanding of engineering design as aspects of the curriculum. Technology, the school subject, is now being seen increasingly in these quarters as a logical place in the curriculum where science and engineering can be enacted.

Design and inquiry have been under consideration here, because these intellectual processes are being viewed as sharing sufficient commonality to be bases for curriculum accommodation. As has been illustrated above, especially in the work of Kolodner (2002), Crismond (2001), and Benenson (2002), some researchers have been exploring the prospect of design as the basis for teaching scientific concepts. This development is critical, to any accommodation. Further, it poses a challenge to technology educators to go further than rehearsing design by way of a generic process, and instead paying greater attention to the content of design. Rote design in technology education classrooms that does not venture into explanation of underlying scientific principles constitutes a disservice to children. Content-independent design has its place, where the intent is to provoke ingenuity. As has been shown above, design and inquiry possess divergent qualities. There is a place in the technology education curriculum for drawing upon the functional knowledge of children where the intent is to promote "designerly thinking" (e.g. France & Davies, 2001; Hill & Anning, 2001;

Gustafson, Rowell, & Rose, 2001). Children must learn how to find design problems and how to pose design problems. But there is also substantial intersection between scientific inquiry and engineering design, and, hence, there must also be a place for design that is premised upon an understanding of scientific concepts.

The convergences that are possible between design and inquiry make for exciting possibilities in the curriculum, between science and technology education, in ways that must now be based upon mutual regard. For science teachers it means new possibilities for contextualizing their subject, in ways that could make the content more appealing. Practical technological design projects can be the basis of making science content more appealing. A solar energy project could be the basis of teaching physics concepts. For technology education teachers, it means adding a new academic dimension to their subject, showing children the relation between artifacts and nature. A super-mileage vehicle becomes an integrating project, in which science, mathematics and technology come together coherently for students.

The convergences we see between science and design also point to opportunities for collaboration between science and technology teachers on the common ground of instruction and curriculum. These two types of teachers clearly can benefit their students by working together to cement natural connections between the subjects. There are clear professional development implications here, for practicing teachers, as well as for pre-service teachers, and the teacher education curriculum. Beyond implications of this order, there is a clear need for rapprochement between the respective communities of practitioners, to address the needs and possibilities that collaboration could engender for the development of curriculum and instructional materials supportive of science/technology teaching.

Design and the role it plays in engineering and technology education is another contemporary issue in technology education, raised as much by practice and politics, as through the standards. As technology educators encounter engineering education curricula in schools and look to both historical and contemporary liaisons with engineers in universities, the issue has raised significant debate.

V. Coming to Terms with Engineering Design as Content

With the publication of standards for teaching, learning, and the inculcation of technological literacy (International technology Education Association, 2000), technology education in the United States has made a significant leap forward toward greater acceptance as a valid school subject. Standards represent content terrain claimed by a community of practitioners, and once stakes are put down, it is left to adherents to move in seeking title. It is doubtful whether we will witness a rush towards bio-technology or medical technology, new areas in the standards that do not naturally issue from our accustomed traditions. But for design there will be great interest since this is a content area that the field has long toiled over. *Design* is arguably the single most important content category set forth in the standards, because it is a concept that situates the subject more completely within the domain of engineering. Four of the 20 standards address the question of design directly. Standard 8 deals with the *attributes of design*; standard 9 with *engineering design*; standard 10 with *trouble shooting, research and development, invention and innovation,* and *experiment in problem solving*; and standard 11 with the *design process*.

It is not inconsequential that the foreword heralding the standards is authored by William Wulf, in his capacity as President of the National Academy of Engineering. This is a significant benediction for a subject whose advocates have for the past decade or so been of the view that its acceptance by the public and by the dominant academic culture of schools turned on the degree of rapprochement that could be worked out with the science as well as the engineering communities. The *Project 2061* curriculum standards acknowledged the common epistemological ground shared by science and technology as school subjects, embodied in the designed world (American Association for the Advancement of Science, 1993; Johnson, 1989). With ties with science thus formalized, engineering was but a step away. The sentiments expressed by Bensen and Bensen (1993) foreshadowed what appears now to be a significant opportunity for the field of technology education to lay claim to aspects of engineering as part of its curriculum purview. Arguing that the subject should assume the name *engineering and technology*, they wrote: “it is imperative that we engage the engineering profession, the companies that employ them, the universities that educate them, and the associations and accreditation bodies that set the standards and benchmarks for them, to become involved in bringing the curriculum into the twenty-first century” (p.5). These sentiments are now shared by important professional engineering bodies, such as the Institute of Electrical and Electronics Engineers (IEEE), as can be seen in the strategies set forth by this body at its *Technological Literacy Counts* conference. The prevailing sentiment was that cementing ties between the subject and the field of engineering had become a high priority, such ties to include joint curricular endeavors (Institute of Electrical and Electronics Engineers, 1998). Writing from the vantage point of the National Academy of Engineering, Pearson and Young (2002) emphasized the need to make engineering accessible to all citizens through the inclusion of engineering design in the curriculum.

The climate for engagement with engineering is now inviting; technology education is being viewed favorably as a credible means of advancing the goal of technological literacy for all, and a means by which students can gain insights about and interest in engineering careers.

This chapter addresses the challenges posed by engineering design as a content area of technology education. What adjustments will technology teachers have to make in their approach to teaching and learning when they teach design as engineering in response to the new standards? How faithful to engineering as practiced must their approach be? There is already some advocacy in the literature that greater attention will need to be paid to mathematics and science, where these subjects underpin design. Cotton (2002) has proposed that mathematical theories should be applied to design in technology education classrooms, and that students should be encouraged to use mathematics to predict the outcomes of their designs. Neumann (2003) suggests that students should spend more time engaged in research and re-design activities, as is the case in British schools. Roman (2001) has encouraged an integrative approach to design that incorporates mathematics and applied science, in keeping with the cross-cutting nature of engineering. Afoot here is a discourse on curriculum integration that raises challenging questions for the field, including whether technology teachers as normatively trained, are equipped to venture into the teaching of engineering design.

Westberry (2003) has laid groundwork for the issues that are to be taken up here, by calling attention to alternative models of design, and exploring the challenges inherent in teaching it across the grade levels. This section necessarily pays attention to approaches to design, but it especially also examines design pedagogy within engineering education. How is design taught to engineers? What logics underpin such teaching? The structure is as follows: (a) the design/problem solving literature of technology education is reflected upon, (b) the question "what is engineering design?" is explored, (c) approaches to the teaching of design in engineering education are examined, (d) reflections on engineering design follow, and, finally, (e) conclusions and implications inherent in coming to terms with engineering within technology education are set forth.

Design/Problem Solving in Technology Education

Design has been a focus in the practice and literature of technology education, often embedded within discourse on problem solving. Its prominence has increased with the shift in American curricular thinking about the subject from a disciplinary to a process focus (e.g. Savage & Sterry, 1990). De Luca (1991) provided a survey of problem solving approaches employed in technology education classes, surmising that design activities teach students how to think, once the learning environment created by the teacher is conducive to creative behavior. Johnson (1988) examined the problem solving literature of technology education and proposed a model for research comprised of three components, the solver, the solving process, and the problem. He suggested that the model could be used to investigate problems relating to trouble shooting or designing.

Employing the model empirically he found differences between expert and novice problem solvers (Johnson, 1989; Johnson & Chung, 1999). In one study, the primary performance difference between novices and expert trouble shooters was found to be the quality of information acquired and the quality of the hypotheses they generated in solving problems (Johnson, 1989). In a subsequent study, Johnson and Chung (1999) used think-aloud problem solving methodology to compare cognitive performance of an experimental group over a comparison group. The approach helped learners evaluate trouble shooting hypotheses, and potential faults in a system.

One dimension of the design/problem-solving literature has focused upon the critical question of the professional development of teachers. Zubrowski (2002) examined the integration of engineering and science via a three-phased pedagogical model comprised of exploration during which students mess about preliminarily, introduction of a standard model, and improvement of the preliminary model. This model was used as the backdrop for designing engineering projects. He found that the approach fostered the teaching of science, as well as interdisciplinary collaboration among teachers. Koch and Burghardt (2002) described teachers' involvement in action research, as they developed design challenges for their students. Here too, design was said to have fostered curriculum integration.

Another focus of the design/problem solving literature has been upon learning in the elementary grades. Denton (1994) examined reactions of children to design and technology simulation activities aimed at teaching them about industry and economics. The motivation of students improved as they made connections between simulations and regular design work. Foster and Wright (2001) found that children increased their technological capability and technological knowledge, having participated in design and technology activities. Gustafson, Rowell and Guilbert (2000) examined children's awareness of structures, finding that they can work out regimes for testing and evaluating the strength of a structure represented on paper.

Addressing an area of need in the teaching of design and problem solving, Custer, Valessey, and Burke (2001) validated an instrument for assessing student learning. The work was premised on the view that problem solving can be reduced to a set of discrete observable behaviors that can be captured via appropriate rubrics. Assessment in technology education is still an undeveloped aspect of the subject, and when associated with the teaching of design it will pose its own peculiar challenges. Just what are students expected to learn when they are taught design, and how is their knowledge to be ascertained? How does the context of engineering alter the way in which we might approach the assessment of design?

Orienting the conversation on design toward creativity, Lewis, Petrina, and Hill (1997) suggested that problem finding has been a missing dimension of the design/problem-solving literature, contending that it is just as important in technology education classes to have children pose problems as it is to have them solve them**.** The centrality of problem finding or problem posing in design/problem solving can be seen in seminal contributions to the creativity literature, notably Getzels, 1982; Getzels and Csikszenthmihalyi, 1976; and Wertheimer, 1968. In his *Productive Thinking*, Wertheimer (1968) set forth more than merely solving problems, thinking involves discovering—probing deeper into questions." Mumford, Reiter-Palmon and Redmond (1994) contend that problem posing contributes to creative problem solving, and that it is inherently a cognitive activity. The new engineering thrust of technology education will require that problem posing be given at least as high a priority as problem solving. Children will have to be taught to imagine—to think like engineers, making observations in the world around them and finding areas of need for which technological design would be central to the solution.

What Is Engineering Design?

Since design stands at the core of both craft and engineering traditions its meaning and usage in technology education is not always settled. Where craft design draws on aesthetics primarily, engineering design has both creative as well as rational dimensions (e.g. Cross, 2000). It is necessary that the conception of engineering design that becomes normative as technology education teachers interpret the standards be an authentic depiction of design as it is conceived and practiced by engineers.

Nature of Engineering Design. While engineering design is an agreed upon cognitive activity, there are nuances in how it is conceptualized. One dominant view is that design is the essence of engineering, an aspect of human ingenuity upon which the competitiveness of countries depend (Koen, 1994). Koen (1985, p.50) has written further that engineers work at "at the margin of solvable problems" proceeding from the known to the unknown. They work under conditions of change, uncertainty, and resource constraints. Koen explains that unlike scientists who proceed within the framework of scientific laws, engineers employ heuristic laws to arrive at design solutions. Heuristics do not guarantee solutions, but they reduce the search time in solving a problem.

Koen devised a taxonomy of heuristics that can be employed in engineering design, comprised of the following elements: (a) *simple rules of thumb* (e.g. one gram of uranium yields one megawatt of energy), (b) *factors of safety* (not trusting pristine calculations and adding a compensatory factor— such as to the calculated wall thickness of a pressure vessel), (c) *attitude* heuristics (such as the maxim that the engineer should always be ready to give a back-of-the envelope answer to peculiar engineering questions), (d) *risk* heuristics (e.g. approaching new problems by making only small changes in what has worked, and (e) *resource allocation* heuristics (including allocating sufficient resources to the weak link in the design).

Pahl and Beitz (1996) write that the main task of engineers is to:

> apply their scientific and engineering knowledge to the solution of technical problems, and then optimize those solutions within the requirements and constraints set by the material, technological, economic, legal, environmental and human-related consideration. (p. 1).

Beyond the technical, design can also be situated in the realm of the *psychological*. It is creative, requiring grounding in mathematics and science, as well as in domain specific knowledge and experience. Design has systemic aspects, requiring optimization of given objectives within partly conflicting constraints. These authors identify types of designs, goals and methods. Types include: (a) *novelty*— new tasks and problems needing original design, which must proceed through all phases; (b) *adaptive*— established solution principles held constant but the embodiment is adapted to changed requirements; and (c) *variant*— sizes and arrangements of parts are varied within the original design parameters (design within fixed principle). Goals include: (a) optimization of function, (b) minimization of cost, (c) aesthetic considerations, (d) ergonomic considerations, and (e) minimization of weight. Solution methods include: (a) *conventional*— e.g. literature search; (b) *intuitive*— inclusive of preconscious or subconscious ideas or insight or flash, brainstorming, or using analogy; and (c) *discursive*—use of design catalogs, or systematic combinations.

Reflecting upon everyday commonplaces (such as the aluminum soda can), Petroski (1996) emphasizes the importance of *failure considerations* in engineering design. He writes that ‘What distinguishes the engineer from the technician is largely the ability to formulate and carry out the detailed calculations of forces and deflections, concentrations and flows, voltages and currents, that are required to test a proposed design on paper with regard to failure criteria” (p. 89). If designing a bridge, the engineer must calculate the load that individual structural members can safely carry before they buckle or come apart, and how much deflection can be allowed at the center of the bridge. Engineers can test a design on the drawing board or computer. Where failure conditions are indicated, the design is modified. Petroski writes that obviating failure is a design principle. Failure considerations extend beyond the technical to the environmental or aesthetic.

As can be seen above, engineering design is viewed as a creative endeavor that proceeds in an environment of uncertainty, from known condition to unknown. Design solutions are framed by constraints, such as cost and safety. Though engineers are constrained by nature, and must rely upon mathematics and scientific principles, they differ from scientists in the extent to which they draw upon heuristics rather than scientific laws in making design decisions.

Design Processes. Engineers rely on a variety of strategies when they design. Cross (2000) notes that these strategies continue to evolve. He points to a trend toward the formalizing of the design process. According to Cross, the new approaches can be classified into two broad groupings, namely creative methods and rational methods. Included in creative methods are brainstorming, synectics such as analogical thinking and bisociation (see Koestler, 1969, p. 59) and enlarging the problem space through dialectics—pitting an idea against its opposite. Rational methods involve breaking a problem into sub-problems, then arriving at sub-solutions. He identifies a general process comprised of seven fundamental design stages, inclusive of clarifying objectives, establishing functions, setting requirements, determining characteristics, generating alternatives, evaluating alternatives, and improving details. Cross makes clear that rational processes and creative processes are complementary, both aiming to improve the quality of design decision-making. Rational approaches to design do not preclude creativity.

The design process is not linear. Hinrichs (1992) points out that c*onstraints* may change in the course of the design, requiring the engineer to switch problem space, thereby making new solutions possible. Components of the design may change as well as the structure. Design is not a discrete engineering phase, Hinrichs points out; rather, it is continuous through significant portions of the lives of projects. Middendorf and Engelmann (1998) concur noting that engineering design is an iterative process requiring numerous decisions. They argue against an omnibus design method, contending that "By the very nature of design, the process used will be different, depending on the type of system or device to be designed, the state of the art, the supporting personnel and equipment available, the number of units likely to be made, and so on" (p .8). Still, they set forth the outlines of a general approach comprised of the following:

> (a) problem definition, inclusive of recognizing a need, and the state of the art; (b) problem evaluation…need analysis, specifications, feasibility; (c) synthesis….study of patents, development of alternate design concepts, determination of the most creative step; (d) analysis…mathematical models, computer simulations, test of physical models, optimize design; (e) communicate and manufacture (p. 11)

They write that in the process of design if little scientific information is available, then, an intuitive approach might be needed. Where such information is available, as in the sizing of boilers, well defined mathematical procedures will be available. Similar general approaches to engineering design have been set forth (e.g. Cather, Morris, Philip & Rose, 2001; Dominick, Demel, Lawbaugh, Frueler, Kinzel & Fromm, 2001).

French (1992) has set forth aids to design, beginning with the use of rough sketches and simple calculations to develop insight into unfamiliar problems. He suggests that the approach to solution ought to be diversified. The designer should proceed stepwise, remembering that ideas do not always arrive in their final form. Initial failures should not be rejected. French recommends seizing the essence of problems by increasing the level of abstraction during solution. One design solution approach he recommends is the use of combinative methods in which design functions are listed, and arrayed in a matrix against all possible solutions by which each can be done, the final product being a morphological chart that offers design options. The best combination of solutions is then determined In a later work, French (1999) set forth a design schema that parallels a more generalized process approach as set forth by Cather, Morris, Philip, and Rose, 2001; Dominick, Lawbaugh, Frueler, Kinzel, and Fromm, 2001; and Middendorf and Engelmann, 1998. The process begins with a need. The client is then questioned and the designer thereby arrives at a clear statement of problem. The problem statement generates broad solutions. The *conceptual design* stage follows, the approach being open ended, searching for schemes to solve the problem. There are tradeoffs between conflicting goals, with the focus being more on function than on form. French contends that this is the phase of the most striking improvements, where engineering science, practical knowledge, production methods and commercial considerations come together. At this stage the designer cannot predict how subsystems might react, or what options may have to be ruled out because of local conditions. Possible concepts or design schemes are then fleshed out such as selecting and sizing major subsystems. Rules of thumb are employed, followed by detailing and refining.

Dym (1994a) contends that the key element in engineering design is *representation*. A design problem may require a multiplicity of representations, such as those needing analytic physics-based models, geometric or visual analysis, economic or quantitative models, or verbal statements not easily captured by algorithms. Such requirements could be statements of function or intent. He agrees that the design process is evolutionary in nature, with choices to be made and alternative paths to follow as it unfolds. The process may include: (a) clarifying the requirements of the client, (2) identifying the environment, (3) modeling the behavior (can the device be assembled?), (4) identifying the constraints (manufacturing, marketing, economic), (5) testing and evaluating the proposed design, (6) examination of whether there is a more economic or efficient design, and (7) documenting the completed design for the client.

Hubka (1982) identifies similar general steps as French (1999) and as set forth in Dym (1994a) but he writes that the process of engineering design also includes a set of *strategic maneuvers*. They include (a) *iteration*— strategies used when a direct solution is not possible and assumptions must be made in order to proceed onward to a solution, (b) *abstraction*— ignoring unimportant steps and concentrating on important ones, (c) *concretization*— moving from rough preliminary solutions to fine tuned ones, (d) *improvement*— starting from a feasible solution, using criticism to improve it. Mullins, Atman and Shuman (1999) include an analysis phase that is comprised of the creation of mathematical and scientific models to study each alternative.

Cross (2002) provides insight into design by looking at the processes employed by three experts, designers respectively of racing cars, sewing machines, and bicycle luggage carriers. He found that though they functioned in different domains these designers shared common general approaches to their work. All three adopted a systems approach to design, rather than a more restrictive approach. All relied upon first principles in their work. For example, the luggage designer focused upon triangulation to achieve rigidity and stiffness, while the racing car designer focused upon the physical forces that acted on a car. Finally, all three explored the problem space from particular perspectives that were dictated by the nature of the design situation and personal motivations, including the desire to provide pleasure to the product user. Cross found that the designers' behaviors could be explained by the concept of the reflective practitioner. He further pointed out that while each operated on a set of common approaches, it was not possible for them to switch between domains, since domain-based expertise required extensive training.

This brief examination of engineering design, its nature and processes, allows tentative comparison and contrast with design as traditionally conceived within technology education. One area of commonality seems to be that there is rough agreement on a general design procedure, inclusive of problem clarification, generation of possible solutions, evaluation of solutions, deciding on a solution, and representation and detailing of it. Beyond areas of commonality is a clear zone of divergence, beginning with assumptions about the knowledge base required by the design engineer. It is evident that engineering designers must posses a combination of scientific, mathematical, and domain-specific knowledge. In addition they must possess *engineering design content knowledge*, consisting of prior experience, knowledge of heuristics, ability to work within tight constraints, ability to make trade-offs, ability to change design in the course of a project, ability to design for manufacturability, and ability to conform to the demands of the customer. Engineering designers must sort through conflicting goals as they seek to optimize function. The starting point of design may vary and may include re-design.

Design in Engineering Education.

Despite general agreement in the literature that design lies at the core of engineering, how it should be approached in the engineering curriculum at the university level is still unsettled. Dym (1994b) observes that design is still an area of contention, with some in the engineering community believing it lacks definitive content and rigor, while others contend that creativity cannot be taught. In a special issue of *Engineering Education* devoted to the teaching of design, authors examined the tensions. McMasters and Ford (1990) expressed the view that schools of engineering should understand that engineering and design are synonymous. Noting that conceptions of design were not stable, they wrote of difficulties surrounding its inclusion in the college engineering curriculum. West, Flowers and Gilmore (1990) lamented that design and build projects get low priority in the curriculum, with the tensions centered on the questionable value of hands-on learning.

Peterson (1990) wrote that unlike engineering science, “Design…is not a science and has no rigorous rules for progression. Both as taught and as practiced, it is almost invariably interdisciplinary. Design projects typically specify only desired performance, leaving task definition and solution synthesis to the student.” (p. 531). He cautioned that under prevailing pedagogic conditions, too little attention is paid to “creative questioning” (p. 530).

In the years since this special issue, design in the engineering curriculum has become an area of heightened focus. The ensuing literature provides glimpses into how engineering schools seek to provide their students with design competence. The approaches vary; in some programs design is offered as a capstone course and in others as a first year course.

Harris and Jacobs (1995) described a capstone-project approach to design teaching. The method they adopt includes five phases, namely, conceptual design, analytic design, detailed design, construction and testing, and competition. These authors distinguished between problem solving and design. They add that whereas typical engineering problem solving provides all necessary information to solve a given problem, real design problems are open ended.

Wild and Bradley (1998) proposed an engineering program featuring a *concurrent approach to design*. Concurrent design moves design away from a linear approach to problem solving. The basic design process is supported by theories including: (a) *design for assembly* (DFA)— providing production information at the stage where alternative conceptual designs are being considered; (b) *design for manufacture*— part of the detailed analysis of the best conceptual design; (c) *quality function development*— which adds customer information to the process; (d) *failure modes and effects analysis* (FMEA)— which enhances product reliability by heading off failure at early stages of design, (e) *Taugushi method analysis*—quantifying cost at production and at consumption point; and (f) *rapid prototyping*—used to connect design to prototype. These authors divide the process of design into conceptual and analytic phases.

Mullins, Atman, and Shuman (1999) found that one semester of engineering design led to improvement in the sophistication with which students approached the design process, but not in the quality of their solutions. They used techniques such as verbal protocols to document and measure students' engagement in the design process. Petroski (1998) described an approach to teaching a first year engineering design course in which students were required to improve the Gem paper clip. He writes that while conventional wisdom says that first-year students do not have the requisite analytic tools gained through engineering design courses, it is possible to challenge them meaningfully through his approach. The course required no prerequisite, yet provided a multidimensional experience and challenge including exposure to the patent system. The Gem paper clip has faults of function and form, allowing students to see "the nature of design, which is how to solve a problem of function while not introducing more new problems, i.e., by keeping undesirable consequences to a minimum" (p. 445). Petroski writes that design always entails compromises and tradeoffs, thus:

> What students learn through the exposure to a score or more of paper clip patents …is that while patents may fairly present a new design as an improvement over the prior art, with each new design also come compromises. To make a paper clip that grips better, one risks having one that that also tends to rip papers more aggressively upon removal. To make a paper clip that has a greater capacity than a standard Gem, more wire must be used and so the clip must be more bulky and more expensive to manufacture. (p. 446)

Pace (1999) described a structured approach to teaching mechanical design principles in an engineering foundations course at an English university. The course adopts a *product analysis* approach**.** Students are presented with an artifact that must meet the following basic criteria: (1) be the embodiment of mechanical principles, (2) perform a simple-to-understand, interesting function, (3) be available in alternative designs for comparison, and (4) be testable for functional performance using desk-top apparatus. An interesting aspect of Pace's account is the importance he attaches to the fact that English students are exposed to design and making (or technology education) in the school curriculum ahead of their attending university and seeking a degree in engineering. Students are aided by having taken this subject in their high school years.

Koen (1994) examined the teaching of design, concluding that the behaviors of practicing engineers are not necessarily the same as those of engineering students. He hypothesized that design is really a set of behaviors. Experts can give a quick answer if that is needed, based on experience. Thus, “To teach engineering design is to develop a strategy for changing the repertoire of design behaviors of the student to that of an acceptable professional engineer using principles of behavior modification” (p. 194). In this vein, Gerhard (1999) described a behavior modification approach to teaching engineering design.

Of considerable interest because of its K-12 implications, Carroll, (1997) described a project in which elementary school children were introduced to engineering through a bridge building exercise. Materials were prefabricated by engineering students, but the children engaged in the actual building. The project allowed possibilities for integrating the curriculum, with aspects of the bridge helping the teaching of geometry, reading, social studies, and physics.

Design in engineering classrooms has been the basis of empirical examination. Napper and Hale (1999) reported on an assessment project aimed at determining the effectiveness of capstone design courses in selected engineering programs. The data were video-tapes of seniors presenting their prototypes and final designs. The projects were evaluated on a set of design criteria specified by the Accreditation Board for Engineering and Technology (ABET). An important outcome of the project was increased awareness of the difficulties inherent in assessing student designs.

Koehn (1999) reported on a study aimed at determining how undergraduate and graduate students and practicing engineers from one university rated the importance of selected ABET criteria as aspects of the civil engineering curriculum. The criteria were: (a) engineering codes and standards, (b) economic factors, (c) environmental effects, (d) sustainability, (e) manufacturability (constructability) (f) ethical consideration, (g) health and safety issues, (h) social ramifications, (i) political factors, and (j) legal issues. Two of the constraints, environmental codes and standards and manufacturability (constructability), were rated highly by both the students and practitioners. Rated low were social ramifications and political factors.

Reflections on Engineering Design

A first important lesson learned from looking at design within engineering, and engineering education is that while it is central to the discipline, there is not consensus as to how it should be treated in the curriculum; and indeed, whether it should be included at all is still a matter of debate. One still unsettled question is whether design is a rigorous enough area of engineering to warrant curriculum treatment. Where it is included, there is some disagreement as to whether it should be taught early or late in programs, or whether it should be infused across the curriculum.

However, there is general agreement on what constitutes design in engineering, how designing should proceed, and what role domain knowledge plays. There is also agreement that design is a fluid process which can be segmented into stages. Some of these stages, such as need identification, invention, evaluation of alternative designs, are well known to technology education. But the distinction that French (1999) makes, between *conceptual* and *analytic* stages of design is extremely useful, showing the importance of contextual and engineering science knowledge, as well as inventiveness, in design decision making. More importantly, this division of design phases may suggest a way in which technology educators can delimit their work.

French (1999) writes that the conceptual stage of design "is the phase where engineering science, practical knowledge, production knowledge, production methods, and commercial aspects need to be brought together, and where the most important decisions are taken" (p. 3). This way of conceiving of the stages of design appears to be approaching consensus proportions (e.g. Harris & Jacobs, 1998; Middendorf & Engelmann, 1998; Wild & Bradley, 1998). As indicated above, Harris and Jacobs (1995) reported that conceptual design and analytic design were key phases of their pedagogic approach when teaching a mechanical engineering design course. The object was to create an egg-carrying buggy powered by an internal combustion engine. The conceptual design phase focused on arriving at a suitable design. They write:

> Immediately following the completion of the conceptual design, work commences on the analytic design to prove the functionality and endurance of the overall device and its components. Analytical designs typically commence with the establishment of overall speeds and loading, static and dynamic. These are translated into component loading, stresses and deflections. Depending on the component, thermodynamics and heat transfer analyses may be required in the determination of loading and stresses. The stresses are compared against the strength data for the initially selected component materials, and if necessary, alternate materials may be selected to meet yield and fatigue resistance. (p. 346)

Upon reflection, it would appear that conceptual design is within the normal purview of technology education. Analytic design poses a challenge. It is the point at which we arrive at a black box, when children construct the tallest tower, or design the fuel-efficient vehicle without understanding why. The question that arises is whether we would have done our part as a field if we delimited our role to conceptual design? One view emerging within technology education is that we could go further, into analytic design. Thus, the underlying science and mathematics should be taught students, to help them make predictions about their designs (e.g. Cotton, 2002; Roman, 2001). This line of thinking has its merits, and could be an area of much discussion, with implications for how the content knowledge of technology education teachers must be considered.

For clues to how we might think about this question we could reflect upon the debate whether design should be taught to first-year engineering students. The question arises because in the first year, students would not yet have been grounded in the engineering sciences. Petroski's (1998) response to this is that it is possible for first-year engineering students to learn "the nature of design" through his paper-clip re-design problem. Students also have opportunity to learn first hand "the nature of engineering drawings, materials, manufacturability, economics, ergonomics, etc." (p.446). Some of his students even devise experiments to test their solutions. All get an opportunity to critique their own designs. Petroski's point is that even without an analytical design phase, his first year design course achieves significant learning objectives.

Pace's (1999) description of the use of product analysis as a means of teaching design is worth noting because the approach seems to be in keeping with established technology education traditions. Students take apart machines and tools routinely. Those same acts can now be the basis of their learning of engineering design, though they will come to the same limit as with conceptual design, when technical analysis is required.

Implications for Practice

Design in technology education corresponds in important ways with the design tradition of engineers. In both cultures, the open-ended problem in which the designer ventures from the known to the unknown is considered the prime challenge. Both come to the conceptual stage of design, where options are evaluated, taking into account design parameters. The engineering culture, more than the technology education culture, pays much attention to customer needs, to the question of trade-offs and constraints, to code requirements, to failure considerations, to manufacturability, and to underlying science and mathematics. In practice, engineers rely on a memory bank of solution strategies that have worked in the past; they also call upon heuristics where quick estimations are needed.

The above examination of design from the perspective of the engineering profession, including insights from engineering education, provides the backdrop for ensuing comment on the challenges and opportunities for technology education as practitioners strive to come to terms with engineering. The comments are framed in terms of (a) what are the boundary limits of technology as it seeks to adopt engineering design as content? (b) how should content knowledge supportive of design be considered? (c) what should technology education teachers know, to be able to teach design competently? and (d) what are the new possibilities for research?

Boundary Limits. One challenge for technology education is how authentically can it interpret engineering design? This issue is settled with respect to conceptual design, which clearly has informed design teaching in schools. But it remains open with respect to analytic design. How should the field deal with the limit of analytic design? One defensible option would be for technology educators to accept this limit, and to view conceptual design as the extent of its domain, in much the way that Petroski (1998) approaches the teaching of design to first year engineering students. The focus is not on calculations, but on learning the essence of design, including critique of design, the role of trade-offs, team-work, invention, etc. A second possible solution might be to approach analytic design in a limited way by including a set of completely worked out engineering design cases in the instructional repertoire of schools. A third option might be to adopt a collaborative approach to design, where technology teachers team with mathematics and science teachers, and with practicing engineers in the teaching of design, a strategy that will allow both analytic and conceptual aspects of design to be realized.

Content Knowledge. How much domain knowledge should technology students possess before it is assumed that they can competently tackle design problems? This question has to be given greater consideration now, because of links to engineering. Design in technology education often shows itself in the form of a space to be spanned by a bridge, a tall tower to be built, or a structure that will bear load. Students compete to see which individual or group has built the tallest tower, or has constructed the longest bridge, or has gotten its structure to bear the most weight. Often the teaching episode ends when a winner is identified, without students' gaining understanding of the reasons behind the success or failure of their attempts. That kind of rote approach to design misrepresents and grossly simplifies the task of the engineer, and perhaps more critically, it inhibits student creative performance, a critical aspect of which is possession of requisite content knowledge (e.g. Lubart & Sternberg, 1995).

Two scenarios that arise on the question of the importance of domain knowledge are (a) whether the intent is to teach just the generic *process* of design, or (b) whether it is to facilitate the solution of a design challenge within a particular domain. In the former case, it is conceivable that the teacher could proceed without consideration of domain knowledge. He/she could rely upon commonplaces (everyday materials or artifacts) about which the *functional knowledge* of students is assured, and could teach in a domain-independent manner. In the latter, students will need some degree of requisite pre-knowledge, depending upon the domain, whether electronics, materials, or construction. Since design in technology education could proceed along the two lines suggested above (content independent and content dependent) there is need in the discourse of the field to distinguish between them. Each approach has an important and peculiar purpose.

Teacher Competence. Just what should constitute the repertoire of technology education teachers if they are to teach design competently? Consistent with comments above with respect to student learning, the implications for teachers is that they would need at minimum to possess some measure of domain knowledge in the main disciplinary areas of the standards (such as manufacturing, construction or transportation). Teachers should also possess some agreed upon competence level in mathematics and science. There are implications here for the re-tooling of both pre-service and in-service teacher development programs. Moreover, teachers would need grounding in design practice, competence that they could acquire through industrial internships.

Research Possibilities. Design offers many opportunities for inquiry in technology education, beginning with the challenges that attend its teaching and student learning. Such inquiry could span areas such as effective methods of assessment of student learning and effective teaching strategies. A more complete conception of the possibilities will emerge once the field works out an appropriate conceptual framework. Ultimately, such a framework can conceivably be informed by discourse streams such as multiple intelligences, learning styles, creativity, and cognition (e.g. Cropley, 1997; Houtz, 1994; Sternberg, 1990).

Conclusion

In this section we have considered the adjustments to be made within technology education for the field to come to terms with engineering as content. These adjustments have been shown to span not just curriculum and instruction but also inquiry and teacher preparation. Adjusting to the design imperative will be a more realizable proposition if technology educators seek to improve their competence by immersing themselves in environments where engineering design is practiced and by actively collaborating with such practicing engineering designers. The higher the degree of collaboration that can be forged with practicing engineers, the more likely it will be that teachers will overcome initial tentativeness, and that they will teach design authentically. The result will be a greater chance that students will have authentic design experiences.

Both inquiry and design are a result of personal creativity. This fundamental construct is often overlooked in technology education literature.

VI. Creativity—The Missing Link in the American Standards for Technological Literacy

The academics-driven reform movement of the last two decades, with its focus on international comparisons of student achievement, high stakes testing, accountability, and the development and specification of content standards for individual subjects, has proceeded on a wholly rationalistic course with the focus being almost exclusively on pure cognition. It would be foolhardy in this environment for any subject not to conform to reform dictates—especially subjects such as technology education whose normative status in the curriculum remains contested. In this vein, the publication of standards for technological literacy by the field (International Technology Education Association, 2000) can be seen as sensible not only on an epistemic front, but on the political front as well. The subject is better placed to dictate its own terms in the American curriculum, now that its content perimeter is better defined.

But while technology content standards are an imperative in bringing about clarity in the curriculum as to what children should learn, and what needs to be taught, they fall short as a way of dealing with aspects of the subject that are ill-structured, and that strive to inculcate dispositions not readily measurable by standardized achievement tests. Subjects for which aesthetics and creative performance are critical curricular dimensions (such as art, technology, physical education, and music), and which are accommodative of students across the range of intelligences, are not readily or completely captured by content standards. Content knowledge in these fields that target student achievement as conventionally conceived, must be complemented by treatment of more subjective and elusive goals such as the development of connoisseurship, appreciation, or creative insight.

Technology takes its place with subjects such as art and music in the extent to which it is an area of the curriculum in which developing the creative talents of children is paramount. The need for focus upon creativity in technology education is ironically made more urgent by the publication of standards for technological literacy because of the prominence now given to the teaching and learning of design. Technological design is a medium through which dimensions of children's creative abilities can be stimulated and augmented. This creative potential of design teaching can be seen in the work of Druin and Fast (2002), where Swedish children who are included in the design of technology reveal inventive dispositions in their journaling. Arguably, stimulating creative impulses in children through design and problem-solving activities is as grand a goal of curriculum as is the achievement of particular design-based measurable outcomes. However, it is an area of the curriculum that is virtually unexplored in the standards, not so much by unwitting or deliberate omission, but because creativity does not quite respond to the inquiry questions that yield content. As Bruner (1962) pointed out, creativity is a silent process, which by its very nature will not be responsive to the reductionist processes that are employed to determine content standards. Instead, it requires its own set of questions, including examination of its nature.

This chapter seeks to stimulate a conversation about the inculcation of creativity as an important goal of technology education, in direct response to its exclusion from the *Standards for Technological Literacy: Content for the Study of Technology* (ITEA, 2000). The purpose is to direct the attention of the field to this relatively unexplored aspect of the subject. While there has been ample treatment of the sub-areas of design, and problem solving in the standards, there is a need to set these processes against the backdrop of a larger and more holistic conceptual framework. Creativity has compelling claims to being the anchoring idea in such a framework. Should a conversation on the creative dimension of technology education blossom to the full, the result could be the unearthing of issues and challenges that could become the basis of a framework for research and for re-consideration of technology-based curriculum and instruction. It is worth noting here that creativity in the context of the teaching of technology education has been identified as a pressing research need for the field (Lewis, 1999).

Discourse on creativity is an important adjunct to discourse on content standards. Where it differs from a content focus is that the emphasis shifts more decidedly to students, beyond what they can learn about technological concepts and processes, onto what they can learn about themselves by engaging technology. In laying the groundwork for a conversation on creativity, this chapter addresses the following (a) creativity (b) creative cognitive processes (c) schooling and creativity (d) creativity and technology education, and (e) implications for technology education.

Creativity

Creativity is not easily defined, because of its unseen character. As Boden (1994) points out, inventors often do not know the source of their insight. Still, it is possible to discern the creative from the ordinary. Bailin (1994) notes that while there has not been universal agreement on what constitutes creativity, there are shared beliefs about its nature as follows: (a) that creativity is connected with originality—with a break from the usual, (b) that the value of creative products cannot be objectively ascertained since there are no standards by which new creations can be assessed, (c) that beyond products, creativity can be manifested in new and novel ways of thinking that break with previously established norms, (d) that existing conceptual frameworks and knowledge schema impose restraints on creative insight, and (e) that creativity is a transcendent, irreducible quality.

An enduring definition provided by Bruner (1962), is that creativity is an act that produces "effective surprise" (p. 3). Bruner explained that the surprise that is associated with creative accomplishment often has the quality of obviousness after the fact. The creative product or process makes perfect sense –once it is revealed. For the creative person, surprise, according to Bruner, "is the privilege only of prepared minds—minds with structured expectancies and interests" (p. 4). Bruner identified three kinds of surprise: predictive, formal, and metaphorical. Predictive surprise is yielded, for example, by path-breaking scientific and mathematical formulas, or by good reformulation of theory. Formal surprise comes about where there is ordering of elements (grouping or patterns) in ways not seen before (as in a musical composition). Metaphorical surprise refers to the connecting of diverse elements through the medium of a common symbol or metaphor.

Lubart (1994) writes that to be creative is to produce work that is both novel and socially useful. Such work may be novel at the individual, societal or international levels, the less parochial the context of the accomplishment, the more highly creative the work. A creative work may have peripheral features, in terms of its importance, quality and production history. It may be important by solving a perennial problem, such as finding the cure for disease. It may show quality through high technical skill. Its production history might reveal the ups and downs encountered along the way to final solution.

Tardif & Sternberg (1988) suggest that it could be fruitful to dissect creativity into processes, persons, and products, and, indeed, much of the research on creativity is framed along these lines. Creative processes take time and include search through a problem space. They may involve transformations of the external word, internal representations through analogies and metaphors, constant definition and re-definition of problems, applying recurring themes, and recognizing patterns. Creative people are governed by internal factors, especially personality. They invariably are creative within particular domains, such as art, music, or electronics. But across domains creative people share common cognitive characteristics such as ability to think metaphorically and flexibly, the ability to recognize good problems in their fields, and the willingness take intellectual risks.

Composite Nature of Creativity

A view of creativity around which there has been a growing consensus is that it is a composite concept, the product not just of individual traits, but also of societal and environmental factors. Csikszentmihalyi (1988) offers such a view, having proposed that creativity is never accomplished by an individual alone, but rather is the product of the interaction of a stable cultural *domain* that will ensure perpetuation of the idea, a supporting institutional framework (a *field)* comprised of the stakeholders and gatekeepers who affect the structure of the domain, and an *embedded social system*. By this way of thinking, attributions of what is creative are relative, and grounded in social agreement.

Creativity and Intelligence

Whether creativity correlates with or is completely explained by theories of intelligence has been a point of conversation in the literature. The idea that seems to be the basis of consensus is that creative behavior has to be explained outside of the framework of intelligence. Guilford (1950) suggested that to fathom creativity one had to look "beyond the boundaries of IQ". He noted that intelligence tests tend to focus on reading and mathematics, subjects that were "not conspicuously demanding of creative talent" (p. 447). Creativity was not confined to geniuses, but rather, on the principle of continuity, it was present albeit in varying degree, in all humans. In vein with Guilford, Sternberg (1985) proposed his triarchic theory of intelligence to allow for creative behavior. Components are: (a) socio-cultural context, (b) experience (novel situations that prompt creative behavior), and (c) componential, the mechanism underlying intelligent behavior.

Feldhusen (1993) writes that creativity has readying and predisposing conditions, one being intelligence, but that while intelligence is an asset, it is not a sufficient condition for creative behavior. Sternberg (1988) viewed creativity as the overlap of intelligence, cognitive style, and personality/motivation. The intellectual aspect deals with problem finding, and problem definition and redefinition, as well as knowledge acquisition related to insight. Cognitive styles include meta-cognitive competence. Personality factors into creativity in terms of traits such as tolerance for ambiguity and willingness to surmount obstacles.

Theories of Creativity

Several strands of theory support inquiry into creativity. Busse and Mansfield (1980) suggested seven lines, namely, psychoanalytic, Gestalt, associationism, perceptual, humanistic, cognitive developmental, and composite theories (such as Koestler's (1969) *bisociation*). Houtz (1994) condensed these lines into four approaches, namely (a) asociationism/behaviorism— connection among disparate ideas, and between stimulus and response (especially Mednick, 1962), (b) psychodynamic, focused on conscious and unconscious thought (thus inclusive of the psychoanalytic), (c) humanism, focused on intra-individual life forces and motivations, and (d) cognitivism, focused on thinking processes and skills. These two categorizations clearly intersect, and together they help frame and inquiry agenda for creativity.

Space does not allow treatment of each of these theoretical frames. Still, for purposes of this section two enduring conceptions suggested by theory, *divergent thinking*, and *productive thinking*, are reflected upon briefly here, because they seem to provide solid conceptual backdrop for the core technological processes of design and problem solving that are so central to standards for technological literacy.

Divergent thinking was included by Guilford (1959) as a facet of his structure of intellect. In this work, Guilford proposed that intellect was composed of thought processes or *operations*, *contents* that are the raw material of operations, and *products* that are outcomes of operations. Divergent thinking and convergent thinking were included among operations. Convergent thinking yields fully determined conclusions drawn from given information. It is associated with general intelligence. Divergent thinking yields a variety of solutions to a given problem. Guilford (1967) found divergent thinking to be composed of four factors: *fluency*, ability to produce many ideas; *flexibility*, producing a wide variety of ideas; *originality*, producing novel ideas; and *elaboration*, adding value to existing ideas. Divergent thinking is believed to be a characteristic of creative minds (e.g. Baer, 1993; Wakefield, 1992). It squares with approaches to the teaching of design that require students to brainstorm, and to generate multiple solutions.

Productive thinking is creative behavior as characterized by Gestalt theorists. Wertheimer (1959) applied it to problem solving, suggesting that structural features of the problem set up stresses in the solver, and that as these stresses are followed up they cause the solver to change his/her perception of the problem. The problem is restructured and solutions emerge. Peripheral features of the problem are separated from core features. Duncker (1945) suggested that the act of problem solving involves reformulating the problem more productively. The problem solver must invent a new way of solving the problem, by redefining the goals, and approaching the final solution incrementally via a succession of insights. Duncker found that insight occurs in problem solving only when the solver is able to overcome a mental block, especially that induced by prior knowledge. If the solver thinks of using an object only in the habitual way, where a novel approach is required, creativity will be blocked. He referred to this experience-induced impediment to creativity as *functional fixidness*. If one is accustomed to seeing a box used as a container, one may have difficulty seeing the same box as a platform (see Mayer, 1995).

Divergent thinking and productive thinking are concepts that seem to resonate with pedagogic approaches to design and problem solving normally seen in technology education. They require open-endedness, and willingness to think outside of the box. These two ways of thinking about creativity can be quite useful additions to the ongoing discourse in technology education, on the teaching of design.

Creative Cognitive Processes

Just what are the processes of creativity? Answers are being provided to this question from the research literature, especially from studies that focus upon subjects who are unusually creative. Through phenomenological inquiry, Cross (2002) looked at the creative cognitive processes of three exceptional designers from different domains of design, and found some commonality in their approaches including (1) they relied on first principles both in origination and development of concepts (such as adherence to fundamental physical principles or design basics), (2) they explored the problem space in a way that pre-structures or foreshadows the emergence of design (for example, they may give precedence to providing joy to the user, or they may act in conformance with the dictates of the design situation), and (3) creative design comes about when there is tension to be resolved between problem goals and solution criteria. Using these areas of commonality, Cross fashioned a model that essentially suggests that designers take a broad systems approach to design, but that they also frame problems in distinctive personal ways that seem to issue from their particular personalities.

Also viewing creativity from a systems perspective, Csikszentmihalyi (1996) arrived at his conception of *flow,* the optimal state of experience that yields novelty and discovery. From observation of creative artists, he surmised that creative flow involves feedback that produces enjoyment when novelty occurs. When things are going well in the act of creating, subjects report their behavior to be almost automatic and unconscious. This state of flow seems to be preconditioned by a set of enablers including having clear goals, balancing between challenges and skill, merging action and awareness, and not fearing failure.

Creative Cognition

While much can be learned about creative processes by study of unusually creative people, there is support for the view that creative behavior is not limited to the gifted, but rather that it is a property of the normative human condition. This is what Guilford (1950) referred to as the principle of continuity, an example being the observation of routine flexible use of language among humans (Chomsky, 1957). This continuity approach to creativity has coalesced into the sub-field of creative cognition.

Ward, Smith, and Finke, (1999) contend that human ability to construct an array of concepts from otherwise discrete experiences is evidence of our *generative ability*. Generative ability includes cognitive acts such as retrieval of existing structures from memory, forming simple associations, transforming existing structures into new ones, analogical transfer, and metaphorical thinking. Creative cognition draws upon basic cognitive theory for explanation of human generative potential. It holds that the act of concept learning--a cornerstone of cognitive theory--is creative. It holds further, that the boundaries between creative and noncreative thinking are not sharp. The idea that creativity is broadly cast in different degrees, leads to distinction between *mundane* versus *exceptional* creativity. Evidence of mundane creativity is human ability to produce an infinitely large number of sentences from a finite set of rules. Prinz and Barsalou (2002) contend that we will understand creative behavior better if we see that mundanely creative acts and exceptionally creative ones are alike in that they both "involve the genesis of novelty" (p. 107).

Generative Processes

Among cognitive processes that are associated with creative behavior are metaphorical thinking, analogical thinking, and conceptual combination. Each of these is briefly reflected upon, bearing in mind that they seem to fit naturally with pedagogy and curriculum supportive of the teaching of technological design.

Metaphors. Metaphors are powerful creative tools that allow comparison and categorization of materially unlike entities. They involve mapping across conceptual domains, from a source domain to a target domain (Glucksberg, Manfredi & McGlone, 1997; Lakoff, 1993). By facilitating description of new situations through reference to familiar ones, they allow conceptual leap (Glucksberg & Keysar,1990). Metaphors bring into play the right side of the brain, which, different from the logically oriented left side, is holistically oriented, supportive more of the strategic than the tactical, and can facilitate dealing with ambiguity. They function at the executive level, subsuming analogies, as well as connections by mere appearance, relying on the principle of association to facilitate connections among unlike entities (Genter & Jeziorski, 1993; Sanders & Sanders, 1984).

Analogies. Analogy is a special case of metaphor, its signature being structural match between two domains. Analogical thinking involves mapping of knowledge from a base domain to target domain to facilitate one to one correspondence. An example would be the connection Rutherford made between the solar system and the hydrogen atom (Gentner & Jeziorski, 1993), or the parallelism that can be drawn between current flow and fluid flow in a piping system. Analogies are tactical; they make possible the solution of a given problem by superimposing upon it the solution to a problem in a different domain (Gick & Holyoak, 1980). Thus, early models of the structure of the atom were based on models of the solar system. Airplane flight is analogous to that of birds. The spider-web has been the basis of design of architectural structure.

Conceptual Combination. Conceptual combination is a creative process that can be explained by association or composite theories. It is the process of combining two or more concepts or entities to yield an entirely new creation (Wisniewski, 1997). In nature, the combination of hydrogen and oxygen yields water, a unique product with properties different from the component gases (Ward, Smith, & Vaid, 1997). In the commercial world, the combination of two dissimilar products can yield a composite novel result. For example, a kite combined with water-skis provide a novel recreational vehicle. Seeing the novel combinatorial possibilities inherent in two dissimilar objects requires creative insight, and uncovering how people reason about combinations can be a way to gain understanding of the nature of creativity.

Role of Schooling

Schooling is an important aspect of the development of creativity in children. Support for such development can begin with a curriculum that takes student interest and individual differences (including thinking styles) (Sternberg, 1990) into account. We can gain insight into what an approach to creativity enhancement through the school curriculum might entail by setting forth the six resources identified by Lubart and Sternberg (1995) as being critical to creative performance as framework. These “resources” are: (a) problem definition or redefinition, (2) knowledge, (3) intellectual styles, (4) creative personality, (5) motivation to use intellectual processes, and (6) environmental context. How can these resources be engaged in classrooms?

While students with exceptional creative talent would benefit from curricula that deliberately include a creativity-oriented component, all children stand to benefit when such an approach is taken. Cropley (1997) contends that the inculcation of creativity should be a normal goal of schooling, with the aim being to help all students attain their creative potential. Children should be helped to achieve effective surprise in their work. He outlines a framework of ideas around which a creativity-focused curriculum can revolve—one that overlaps with Lubart and Sternberg’s resources approach. It includes provision of content knowledge, encouraging risk taking, building intrinsic motivation, stimulating interest, building confidence, and stimulating curiosity (Cropley, 1997). As can be seen here, creativity enhancement must address factors that are *internal* to the student, such as personality and intellectual disposition, as well as factors that are *external* (e.g. curricular, social, and environmental).

Domain knowledge features as a key prerequisite of creative productivity in the schemas offered by both Lubart and Sternberg (1995) and Cropley (1997). There is strong evidence in the research literature indicating that a fund of domain knowledge is an imperative for creative accomplishment (Simonton, 1988; Csikszentmihalyi, 1996). Cropley (1997) contends that providing such knowledge is one important way in which schools can foster the development of creativity. Lubart and Sternberg (1995) write that knowledge of the state of knowledge in a domain prevents attempts to reinvent the wheel. Nickerson (1999) offers the view that the importance of domain-specific knowledge in the forging of creativity in underestimated. He argues that across a wide front of domains, including the arts, mathematics, and science, acquisition of a solid knowledge base is a precursor of exemplary creativity. He writes:

> One cannot expect to make an impact in science as a consequence of new insights unless one has a thorough understanding of what is already known, or believed to be true, in a given field. The great innovators of science have invariably been thoroughly familiar with the science of their day. Serendipity is widely acknowledged to have played a significant role in many scientific discoveries; but it is also acknowledged that good fortune will be useful only to one who knows to recognize it for what it is. (p. 409)

It is necessary to offer a caveat with respect to the importance of domain knowledge and it is the contention that prior knowledge could sometimes impede creative behavior. As Lubart and Sternberg (1995) point out, high levels of knowledge can actually stymie creativity. Dunker (1945) referred to this possibility of the problem of *functional fixedness* where one is unable to break away from normative usage of an item. Weisberg (1999) speaks of the tension between knowledge and creativity, suggesting a U-relationship between the two that acknowledges both positive and negative transfer of knowledge. Still, the fact that prior experience or knowledge could conceivably be a depressant on creativity is more a caution than an argument against domain-knowledge acquisition as a basis of expertise and creativity.

Beyond provision of domain knowledge, schools can enhance the creativity of children if classroom environments support and facilitate risk taking, problem posing, individual learning and thinking styles, and intrinsic and extrinsic motivation (Jones, 1993; Jay & Perkins, 1997; Lubart & Sternberg, 1995; and Cropley, 1997). Some school contexts are more supportive of creative behavior than others, and the factors that can militate against creative behavior may be internal and external in character (Jones, 1993). For example, low self-esteem, an internal factor, could inhibit creative effort (Hennessey & Amabile, 1988). The external environment can dampen creativity if it does not reward creative behavior, or if it deliberately suppresses it.

Creativity can be enhanced in the curriculum by providing students more opportunity for problem finding as a precursor to problem solving. Problem finding has not be given as much prominence in technology education as problem solving (see Lewis, Petrina, & Hill,1998). Though there is a compelling literature supportive of the view that the ability to find problems is decidedly creative. For example, Wertheimer (1968) contended that " Often in great discoveries the most important thing is that a question is found. Envisaging, putting the productive question is often more important, often a greater achievement than solution of a set question"(p.141). Problem finding refers to the way that a problem is conceived and posed, and includes the formulating of the problem statement, periodic assessment of the quality of the problem formulation and solution options, and periodic reformulation of the problem (Getzels & Csikszenthmihalyi, 1976; Jay & Perkins, 1997). Mumford, Reiter-Palmon and Redmond (1994) write that problem construction contributes to creative problem solving, and that it is a predictor of real world creativity. Runco and Chand (1994) examined how individuals decide whether problems are worth pursuing, finding that metacognitive evaluation is a key to their method.

Creativity and Technology Education

Technology education is a special place in the school curriculum where creativity can be fostered uniquely. Indeed, the subject is premised upon human creativity—on the ingenious ways in which from the time they stood upright, human beings have devised ways and means to deal with problems that beset them in daily existence to assure their very survival and, ultimately, to improve the quality of their lives. In the long march across time from river crossings in canoes, to space crossings on rocket-powered ships, human beings along the way systematically have relied upon their creativity to overcome existential obstacles, and with each advance have yielded and stored technological knowledge upon which even further advance could be made.

Early forms of the subject have tended to focus upon rehearsing basic overt technological processes, such as tool use and the making of artifacts. As the subject has progressed, there has been retreat from this essentially instrumental focus, toward one where children are taken behind the scenes of human advance and presented with hurdles that can be overcome only through their creative design. This shift of the subject to a place earlier in stage of the process of technological creation, where things are unsettled, and there is no single right answer, has made the subject almost ideally suited to uncovering dimensions of the creative potential of children that would go hidden in much of the rest of the curriculum. While the American content standards in science now include technological design as an area of study (see National Research Council, 1996), the long tradition of technology education gives the latter subject a much greater claim to this content.

Design. The strong design focus of the American *Standards for Technological Literacy* (ITEA, 2000) offers opportunities for teaching to enhance creativity. What makes design so specially suited to the inculcation of creativity in children is its open-endedness. There is more than one right answer and more than one right method of arriving at the solution. The ill-structured character of design requires that students resort to divergent thought processes and move away from the formulaic. As they do so, their creative abilities are enhanced. But despite the potential here, there are indications in the literature that we still have some way to go before creativity becomes a more central feature of the teaching of design in the United States and elsewhere. For example, McCormick and Davidson (1996) cautioned that in teaching design, British teachers were giving precedence to products over process. Others observe that technology teachers in Britain were pursuing a formulaic line when teaching design comprised of stages that were often contrary to the natural design tendencies of children (e.g. Chidgey, 1994; Johnsey, 1997).

This tendency toward teaching design as a process that proceeds through definable stages is evident in the United States as well, noticeable in the *Standards for Technological Literacy* (ITEA, 2000), which states that:

> The modern engineering profession has a number of well developed methods for discovering such solutions, all of which share common traits. First, the designers set out to meet certain design criteria, in essence, what the design is supposed to do. Second, the designers must work under certain constraints, such as time, money, and resources. Finally the procedures or steps of the design process are iterative and can be performed in different sequences, depending upon the details of the design problem. (p. 90)

Reeder (2001) sets forth a set of comparable steps in his description of how industrial design is taught at his university, but included is a conceptual development stage that involves open-ended, divergent thinking.

The problem for the field of technology education in the United States and elsewhere is that overt description of the stages of the design process observable when engineers do their work, has become normative design pedagogy. This stage approach runs the risk of overly simplifying what underneath is a complex process. Teaching design as a linear stage process is akin to arriving at a pedagogy of art by mere narration of the observable routines of the artist. It simply misses the point that design like art proceeds from deep recesses of the human mind. To arrive at a pedagogy of design, there is need to go beneath the externals of the process. The key is to recognize design as a creative rather than a rationalistic enterprise.

Roger Bybee (2003), a strong advocate of the new standards for technological literacy, has written that "Technological design…involves cognitive abilities such as *creativity* (emphasis added), critical thinking, and the synthesis of different ideas from a variety of sources" (p. 26). This creative element requires an approach to teaching that gets deeper below the surface.

We are beginning to see interesting deviations from the normative approach to the teaching of design in the contributions of Flowers (2001) and Warner (2003). Both have taken the approach of intersecting what is known about engineering design with the research and theory on the conditions of creativity, to suggest that there is need for much more than formula in the teaching of design. Flowers suggests that humor in the design and problem solving classroom can promote divergent thinking. Arthur Koestler (1969) gave credence to humor as an important marker of creativity in his landmark contribution *The Act of Creation.* Humor in the creativity-oriented classroom is consistent with the view, embedded in leading theories and research, that creativity has an affective dimension—that it thrives in environments in which intrinsic motivation flourishes. Such environments encourage non-conformist thinking and personality types that thrive better in less structured settings (Eysenck, 1997). Warner (2003) joins Flowers in pointing out that the tone of classrooms can make a difference in the quality of the creations of children. He points out that to support creativity in technology education classrooms, teachers must be more tolerant of failure. Flowers writes that "Teachers of design must maintain a classroom culture that promotes successes but embraces the learning opportunities that failure presents" (p. 10). He draws on research suggesting that some kinds of classroom climates, such as those where competition is encouraged, or where rewards are offered for performance, actually dampen creativity (e.g. Hennessey & Amabile, 1988).

Earlier in this chapter generative cognitive processes such as analogical and metaphorical thinking, and conceptual combination, were identified as means by which creative people have arrived at novel products. Such processes should be included in the pedagogic repertoire of technology teachers. They should be taught to students in design classes in technology education, as devices that can be employed in solving design challenges. We see an excellent example of the how metaphorical and analogical thinking can be infused into the teaching of design in the contribution by Reed (2004) on biomimicry, that is, design that imitates nature. Reed shows that many scientists and engineers continue to look to nature as they contemplate designs and that many industrial products (e.g. Velcro) are inspired by nature. Design pedagogy can benefit from ideas such as biomimicry as prompts for helping students as they engage in creative search. This pedagogy must also be informed by findings emerging from the creativity research literature, especially from studies in which expert designers articulate the logics that underpin decisions they make and actions they take in the act of designing (e.g. Cross, 2002).

Beyond cognitive strategies that are known to yield novel products are the concomitant factors that support creativity, notably the importance of domain knowledge, problem posing, and problem restructuring. We have learned from the literature that domain knowledge is fundamental to creative functioning (Cropley, 1997). And yet, this is an area of the design discourse in technology education that receives almost no attention. Creativity cannot proceed in a knowledge vacuum. While there is a place for the teaching of domain-independent design, where the context is everyday functional knowledge, it is necessary that children be challenged with design problems that reside in particular content domains, such as electronics, manufacturing, or transportation. Children are more likely to arrive at creative solutions when they puzzle over such problems if they are first taught the supporting content knowledge.

Though problem posing ability is an acknowledged marker of highly creative behavior (Getzels & Csikszenthmihalyi, 1976 and Wertheimer, 1968), it remains an almost neglected aspect of the technology education discourse—a discourse steeped in treatment of problem solving. And yet, as Lewis, Petrina and Hill (1998) argued, using principles of constructivist learning in support, we should be as interested in the ability of children to find good problems as in their ability to solve problems. There are implications here for how we arrive at design problems in our classrooms. Are those problems teacher-imposed, or do they originate from the observations of our students?

Akin (1994) calls attention to the creative potential of problem restructuring for increasing the creative potential of design. Drawing from experiences in architecture he distinguishes between anonymous and signature design, and between routine and ill-defined problems. Ill-defined problems are not bounded by available design standards. They require 'the additional functionality of problem restructuring as they cannot be resolved without a framework within which problem solving can operate" (p. 18). According to Akin, within problem restructuring resides great creative potential, capable of yielding signature work. This view that problem restructuring engenders creativity is consistent with the concept of productive thinking (Dunker, 1945; Wertheimer, 1968).

There clearly is a need in technology education for a more textured discourse on the teaching of design than currently obtains. Problem posing, problem restructuring, analogical and metaphorical thinking, and use of humor are pedagogical devices that belong in an expanded view of how the creative aspect of design can be realized.

Implications. Unquestionably, the publishing of content standards represents an advance for technology education. What has been argued in this chapter is that there are aspects of school subjects that cannot be captured by standards, and in the case of technology education, creativity would be an example of such an elusive subject outcome. In a way, this article constitutes a caution to the technology education community that the subject is still a work in progress, and that there are aspects of it that are not given naturally to rationalistic content-derivation methods. We are at a point where the subject in the curriculum from which technology education increasingly takes its queue is science, with its exactness; but it may be that we can benefit from alliances with other subjects, such as art, or music, that have ill-structured aspects, and where students are encouraged to use knowledge not for its own sake, but in support of thought leading to creative expression.

Since there are areas of the new standards, such as design/problem solving, that lend themselves to the inculcation of creativity, one implication of the ideas outlined here is that there is need within the growing standards-based literature for a strand of discourse and inquiry that deals with unspoken but adjunct areas of the standards-provisions. One issue unearthed by this section is the unsatisfactory state of design pedagogy. Another is the relatively unattended area of problem posing. But standing above all is the fact that that there is a dearth of creativity-based scholarship supportive of technology education. This is an overwhelming area of research need for the field.

VII. Knowledge of Technology As Language

Review of how technology education became a school subject, the intellectual heritage of technology education, and contemporary curriculum issues in technology education provides an appropriate background for a point of departure into what should the future of technology education hold with respect to its definition as a school subject and the ideas which should be embodied in the teaching of technology in schools. This discussion must take into account the current state of curriculum and instruction today and the ideas which are prevalent in the theory of education. This, then, leads to a minor theme which has been present in the ideology of technology education throughout the Twentieth Century, that is the role of language and knowledge with regard to technology education and vice versa.

Embedded in all of the reasons for technology education has been an over riding belief in the “hands on” nature of technology and the need for technology education to reflect that nature in the classroom. The importance of the activity and the role of the hands in that activity in technology education dates back to the very first arguments made by Calvin Woodward with regard to the integration of the hand and the eye in order to learn. Woodward created a powerful argument for manual training by addressing the largely abstract and academic nature of schooling and noting the absence of the creative role of using the hands in order to fully educate people. Critical to his argument was the interrelationship of the hand and the eye, the hand and the mind with regard to a complete education. Once manual training had been established in the schools, the arguments about the need for a well rounded education involving using the mind to make and do seemed to have rotated into the background of the thinking and justification for industrial arts and technology education while at the same time using the hands to create became the primary mode of teaching about technology.

Since the time of Woodward, technology educators have privileged activity in the instruction of technology education and industry and technology as the basis for curriculum planning and teaching via the "project approach" of Kilpatrick (Barlow, 1967) through the processes of the IACP (Towers, Lux, & Ray, 1966). While a few elementary school educators did focus on the integrative value of solving practical problems with respect to subjects such as language arts (Bennett, 1937), this emphasis was not the main stream of curriculum in industrial arts and technology education. The reification of activity, while a hallmark of the field, may very well have stunted growth with respect to the role and purpose of technology as an educational endeavor worthy of subject matter status in the schools. An excessive focus on activity has led us to slight the role of language with respect to technology education as a school subject and the potential power of technology as an activity that helps to develop and teach language, as well as, lead to new knowledge.

Surely, we have not ignored language with the creation of taxonomies of technological systems, but even though that work has been done in several notable curriculum projects, the role and import of the language of technology has not been stressed. Taxonomies of technology were created and influenced the creation of texts and instructional materials, then, shelved with the activities in the curriculum guides taking precedence over the language codified in the taxonomies. For example, one might associate making racing cars with the Industrial Arts Curriculum Project rather than remembering the role of taxonomies as manufacturing knowledge and a context for the car activity.

Recently, several technology educators have recognized that constructivism could be important for technology education with regard to the role and purpose of technology in the school curriculum (Herschbach, 1998; Lewis, Petrina, & Hill, 1998; Jaarvinen & Hiltunen, 2000). It is this idea that we would like to explore, especially with respect to the role of language and activity in technology education and the way in which our colleagues in other school subjects see activity promoting the development of language through constructivism.

First, we need to ask ourselves what is education about? What function does educating someone serve? No matter what subject, when we are teaching it is a language-based activity. All educators teach a common language about a subject so that we can communicate with each other about that subject, learn about the subject, and, when we become experts, create new knowledge related to that subject. About language acquisition, Bruner (1990) states

> It is only *after* some language has been acquired in the formal sense, that one can acquire *further* language as a 'bystander'. Its initial mastery can come only from participation in language as an instrument of communication. (p. 73)

Some anthropologists have noted that the increase in human brain size coincides with the increasing development and use of tools. One theory suggests that as early humans taught other humans about tool making they needed to communicate more frequently developing language to do so. This was the earliest form of education. There are lots of other goals and purposes of education, but the bottom line is about learning things and humans learn things through communication with each other. Therefore, no matter what subject is being taught, a language specific to that subject is needed and needs to be taught so that teachers and students can communicate and understand each other regarding their subject. Technology taxonomies achieve the purpose of identifying language which needs to be taught so that knowledge about technology can be shared and created. They also, if appropriately understood and taught, provide a model or schemata (Scarborough, 1981) of knowledge that enables students of technology to organize their knowledge and to categorize and place new knowledge regarding technology. Experts such as engineers use taxonomies of knowledge recorded and stored as language to generate new knowledge about technology (Bransford, Brown, & Cocking, 1999).

More important, however, is the function of human activity with regard to the development and use of language. Vygotsky called attention to the psychological relationship of activity and thought as a result of his research in the early part of the Twentieth Century.

> The rational, intentional conveyance of experience and thought to others requires a mediating system, the prototype of which is human speech born of the need of communication during work. . . communication presupposes generalization and development of word meaning (Kozulin, 1986, p. 9).

Vygotsky provided a psychological argument for the relationship of activity and language with regard to learning. In studying language and learning he related practical activity to language use.

> We saw that this speech becomes gradually intellectualized and starts serving as a mediator in purposive activity and in planning complex actions. Activity and practice are, thus, those moments that help us to uncover previously known aspects of egocentric speech.
>
> Piaget argues that 'things do not shape a child's mind.' But we have seen that in real situations when the egocentric speech of a child is connected with his practical activity, things do shape his mind. Here, by 'things' we mean reality, neither as passively reflected in the child's perception nor as abstractly contemplated, but reality that a child encounters in his practical activity (Kozulin, 1986, pp. 39-40).

In sharp disagreement with Piaget's thoughts on the influence of practical activity on the learning of children and early humans, Vygotsky points out that the practical activities of agriculture, hunting, and manufacturing are almost the entire existence of early humans and the foundation of a child's language learning in the home.

In Vygotsky's arguments regarding the relationship of activity and language learning, technology educators have at least two important avenues to follow. First, in the early education of children, activity, as already noted by a host of educators (Bennett, 1937), is critical to generalization of concepts and the learning of new knowledge. Second, the evolution and preponderant use of technology by humans serves to create new language and concepts that can serve as valuable school knowledge as subject matter, provided that the emphasis is equally on language and activity.

Activity and Learning Language

The renewed interest in constructivism is evidence of the turn towards relating activity and language through context in the effort to educate children. There has been a resurgence of interest on the part of educators in the psychology of Vygotsky and others with regard to cognition and this is of benefit to technology educators, especially those interested in elementary school technology education, who have struggled for more than a century trying to convey and implement educational programs based upon constructivism ideals. From Bonser and Mossman (1928) in their efforts to introduce integrated activity to Illot and Illot (1988) in their research on the effects of activity on children's use of language, they and host of technology educators have intuitively known and have overtly discussed the value of activity with regard to constructing new knowledge. Bennett (1937) has provided a detailed documentation of their early efforts to develop sound educational programming based upon constructivism and the educational literature about elementary school industrial arts and technology education during the past century is filled with further evidence of educational programs dedicated to improving cognition through the use of activities in schools. These efforts to give meaning to learning through activities are reinforced by Bruner (1990) in *Acts of Meaning*, a text designed to refocus cognitive psychology on meaning. In an effort to counter Chomsky's view of learning language and to summarize recent research, Bruner states:

> Language is acquired not in the role of spectator but through use. Being 'exposed' to a flow of language is not nearly so important as using it in the midst of 'doing'. Learning a language, to borrow John Austin's celebrated phrase, is learning 'how to do things with words.' (Bruner, 1990, p. 70)

Again, in an effort to refocus research on cognition, Bruner (1990) provides a glimmer of the possibilities that technology educators could study with regard to the value of their subject matter in the schools.

> the acquisition of a first language is very context sensitive, by which is meant that it progresses far better when the child already grasps in some *prelinguistic* way the significance of what is being talked about or of the situation in which the talk is occurring. With an appreciation of context, the child seems better able to grasp not only the lexicon but the appropriate aspects of grammar and language.(p. 71)

There has been at least one early attempt to study this phenomenon in technology education classrooms, but is has been buried in obscurity and does not exist in a commonly available document. In 1988 Illot and Illot studied children's use of language while performing and discussing typical technology education activities and found that their use of grammar was more complex with respect to verb tense usage as a result of performing and explaining technological activities. Within technology education there are few studies that attempt to replicate or follow up this study.

Technology Knowledge

Not as prevalent in the literature of technology education is the argument that as a major human endeavor, our use of technology not only requires specific language, but also creates new understandings and knowledge and for that reason technology should be an integral part of the schools' curriculum. Technology educators have argued that technology is ever changing and rapidly changing, that technology and industry is critical to the economic development of the country, that learning about technology helps people to make career choices, that study of technology helps people to make wise choices as consumers and voters in a democratic society (Zuga, 1989), but few have ever focused on the language that is to be learned through the study of technology and the role of that language in the education of a child and the successful functioning of an adult in contemporary society.

Technological knowledge has been codified into taxonomies by the technology teacher education community via several curriculum projects dating back to the last half of the Twentieth Century with the most comprehensive listing of content for manufacturing and construction in the *Rationale and Structure of Industrial Arts Subject Matter* (Towers, et al.,1966). This knowledge represents the language that should be taught to children in order to develop their technological literacy. This is the task of this project with regard to two new areas that have been added to the study of technology, biotechnology and medical technology. Identifying and using language about technology is a major part of teaching children about technology. Without technological language as identified in taxonomies, children are asked to make bridges and they are tested on the physics related to bridges while the technological concepts such as the structure of the bridge and the best means of assembling that structure may be ignored. It is not that the physics of bridge construction are not important, but it is that the technology of bridge construction and the relationship of the technology to the physics through making choices about the best way to construct a bridge is what is important to bridge building. Modern bridge design benefits from our knowledge of both the technology as materials and techniques and the physics of stress, loads, and so forth.

As an approach to the study of technology the idea of technological knowledge through language serves both as a focus for instruction as well as a reason for the inclusion of technology education in the curriculum.

> It is only *after* some language has been acquired in the formal sense, that one can acquire *further* language as a 'bystander'. Its initial mastery can come only from participation in language as an instrument of communication. (Bruner, 1990, p. 73)

Technology education creates the contexts in which children learn to use the language of technology. Technology education provides a fertile ground for teaching not only language about technology, but also science, mathematics, and other subjects. However, it is the language of technology that is unique to the field and the language that creates the best argument for requiring technology education as a school subject. As our society becomes more and more sophisticated with regard to its use of technology we must help people to negotiate the myriad of choices that are presented to them through technology and its contextual use.

Technology Knowledge and Language in Context

Language as knowledge of technology is context bound. And, it is in the contexts of technology that language differentiates medicine from manufacturing from construction. However, some of the core language and knowledge of technology is transportable across contexts. There are duplications of processes in each context that indicate both a core of technology and a contextualization of that technology. For example, a manufacturing firm may grind and polish lenses for cameras while an optometrist may grind an polish lenses to treat a patient. One context would be manufacturing, the other medical technology and the processes would be the same or very similar.

Nonetheless, it is context that is both critical to the specificity of technological knowledge as well as the locus for learning about technology. Each context of technology could be seen as a culture in itself, requiring language and interpretation specific to that culture. Regarding cultural psychology Bruner (1990) analyzes:

> A cultural psychology is an interpretive psychology, in much the sense that history and anthropology and linguistics are interpretive disciplines. But that does not mean that it need be unprincipled or without methods, even hard-nosed ones. It seeks out the rules that human beings bring to bear in creating meanings in cultural contexts. These contexts are always *contexts of practice*: it is always necessary to ask what are people *doing* or *trying* to do in that context. This is not a subtle point, that meaning grows out of use, but in spite of its being frequently sloganized, its implications are often unsuspected. (p. 118)

Bruner's analysis is important to technology educators because it could be reversed to help us to focus on the idea of a context of practice where there is a specific type of doing or trying in a context as a technology context where knowledge of technology is created for that specific context and the context helps to create new technology knowledge.

As humans continue to add to our knowledge of technology it is especially the contexts of technology that become confusing because it is the merging of existing contexts that form new areas of research and new knowledge regarding technology. For example, the agricultural and medical contexts have both merged in the study of biotechnology as it relates to the study of genetics in plants and animals and has the possibility of improving human medicine. Overlapping all contexts of technology has been the use, in each, of information technologies to improve productivity and quality. Yet, in each culture, each context, the use of that technology may differ as it fits the needs of the context.

The new standards for technology education (International Technology Education Association, 2000) have introduced the idea of contexts of technology. As we reach out to further define our use of technology for the purpose of teaching about technology we will be able to think more broadly about the relationships between and among the contexts of technology, a core of technological knowledge, and the expansion of the contexts of technology to a context such as medicine which has been addressed in the standards and, in the future, to a context such as food processing and preparation, which has been virtually ignored by technology educators.

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