

1. Reflections of Technology in the Past, Present, and Future

Paul W. DeVore

This article speaks to all members of the many professions of technology. It speaks also to all lay persons who have interest and concern for the world we live in and the world that is to be. It was immediately clear upon attending its presentation that it needed to appear in the very next issue of this journal in service to our readers. So, with agreement of his hosts at Kent State University, who had proprietary rights, Dr. DeVore promptly forwarded the text and thus we faced the challenge of translating a statement prepared for oral presentation for our readers. After reviewing the piece and considerable wrestling, we are pleased to present it virtually in its original form. We controlled the tendency to overedit so as not to diminish the impact and importance of the statement. A few headings have been added, editor's margin notes provide some context, and a few arcane comments (inside jokes) known and understood only by a privileged few in the audience have been removed. JS

DeVore was the keynote speaker at Kent State University's School of Technology Vision 21 Awards Banquet on Saturday, April 4, 1998. He was also one of the 21 distinguished persons honored at the event.

Kent State had its beginning nearly a century ago. William S. Kent, a person of vision, donated 53 acres of farmland located on a hill overlooking a small town on the Cuyahoga River. He did so to establish a teacher education school in his community.

When I visit various communities in my travels, I always ask, Why does this community or city exist? What is its reason for being? Kent exists because of the Cuyahoga River.

The Haymaker Gristmill, established in 1805, was the beginning of Kent. The gristmill used power provided by a waterfall on the Cuyahoga River. Soon after, a village known as Franklin Mills evolved with numerous mills and factories located along the river. These mills formed the industrial center, the economic base, of Franklin Mills. Business was attracted to Franklin Mills from surrounding areas.

By 1863 Marvin Kent was instrumental in bringing the Atlantic and Great Western Railroad to Franklin Mills. And the Pennsylvania and Ohio Canal, served by Pippen Lake and Brady Lake, provided an inexpensive means of transportation for the commerce of the area. Thus, two major areas of technology were the basis for the forming of Kent, manufacturing and transportation.

Today, Kent State University, including the faculty and students of the School of Technology, is at the heart of a changing Ohio industrial area. This area is bounded by the cities of Canton, Massillon, Akron, Cleveland, Warren, and Youngstown.

Excellence, Creating, and Thinking

I have always been fond of libraries and librarians. Connie, my spouse, is a librarian. Librarians are great people! They have helped me extensively throughout my career. Because of my association with the fondness for libraries, I found a cartoon of Hagar the Horrible to be insightful. You may have seen it. In

the cartoon you see Hagar and his troops in the heat of battle. Hagar has his shield up and his sword waving. He shouts to the enemy, "Surrender or die!"

His ever present scribe responds to Hagar in a deferring way, "Personally, I think you should say something a little less extreme, Hagar." Hagar says, "Like what?" The scribe says, "How about, 'Surrender or have your library card revoked for a year?'"

From my perspective the scribe was right on target. Personally, I would rather surrender than give up my library card, unless, of course, the other side didn't have libraries or Internet connections. In my life and professional career, I have discovered that knowledge and information are vital to the good life. They are tools for thinking, for creating.

We are here this evening to honor 21 alumni. These alumni are examples of excellence in our profession. The term excellence, we use so frequently, can be defined as that state of possessing good qualities in an unusual degree.

What are these good qualities? One quality is the inner desire to achieve. People of excellence strive, as strange as it may seem, for the inner satisfaction of knowing and of doing. And they do so without any thought of achieving external rewards.

People of excellence have high levels of motivation. And they have the ability, and they pursue the knowledge and know-how, necessary to attain their goals.

They have a work ethic that focuses on diligence, on doing, and on striving to attain. And they seem to be blessed with a high degree of physical, mental, and psychic energy.

I said I want to start over. And you ask why? And I reply, because the present is so exciting and the future holds such great potential. Each of us has opportunities today that are beyond even those we envisioned in our wildest dreams when we first began our careers.

Dr. DeVore is a Distinguished Service member affiliated with Phi Chapter. During his career he published widely and has been a seminal force in fostering the recognition of technology as a discipline and a field of study deserving the stature of the established school fields. He is Professor Emeritus at West Virginia University where he founded the doctoral program in technology education. Now retired from his position in higher education, as the principal of P.W.D. Associates, he is a consultant of international stature.

The advent of the reorganization of the School of Technology into a college-level academic unit is a recognition of this great potential. It was a masterful move by those involved. By this step this University has established a new beginning.

It is my understanding that one of the honorees here this evening, Tom Barber, was one of the leaders who was instrumental in establishing this new beginning. He deserves high praise for his insight and efforts.

Certainly, the vision behind this reorganization was based on a belief that Kent State University should play a major leadership role in technological studies.

Technology and Wealth

Why do I want to start over? I want to start over because of the important role technological development has played in the health and wealth of nations. I cite from an article written by Robert U. Ayres of Carnegie Mellon University. The title of the article is "Technology: The Wealth of Nations." Dr. Ayres concluded from his research that "most wealth in existence today originated from technological innovation. Labor and capital play a role, but while wealth has material aspects, technological innovation is essentially a form of 'condensed' useful information or knowledge. Its ultimate origin is the human mind."

A contemporary of Dr. Ayres, Professor Solow of the University of Chicago, who received a Nobel Prize in Economics for his 30 years of research into the relation between technology and economic growth, asserts that technology is the key to all economic growth.

As it was in the early days of the village of Franklin Mills, technological knowledge is still the base of the economic growth along the Cuyahoga River, or anywhere else in the world.

I was pleased to find that the School of Technology has recognized this basic fact. It is included in the statement by Dr. Chowdhury on the School's web page. The statement reads: "In that environment of intense global competition, the challenge of preparing 'change agents' and the deployment of innovative technologies is becoming a strategic battlefield of the international marketplace."

This recognition is a true turning point in thinking about the technologies and technological studies. This recognition of the importance of technological knowledge as the fundamental foundation for economic growth will be an important factor in the scheme of things as the faculty and the staff of this School of Technology pursue Vision 21.

It is also basic to the reason why I want to start over.

The Educated Mind and Technological Behavior

A well-known example of the relationship between the origin of wealth and the human mind is the Microsoft Corporation. In recent Congressional testimony Bill Gates made the point that Microsoft must innovate or die.

Bill Gates also understands that the source of invention and innovation is the creative mind. And he understands that the creative mind is a prepared mind, an educated mind.

The prepared mind is at the heart of the creative process in the technologies. From the prepared mind comes the creative acts, the acts of insight. And it is the prepared mind, the educated mind, that will make a difference in the United States being competitive in a global economy and in being able to make a difference in its communities.

Interestingly, the global economy that so many people are talking about has been enabled by a C-level master's thesis—which focused on a new approach to package delivery—coupled with the development of the turbine engine and the computer. Today, this combination is known as FedEx. Jeffrey Garten noted in the March 23 issue of *Business Week*

that FedEx has become the global logistical backbone for many of its corporate customers. It manages their worldwide inventory, warehousing, distributions, and custom clearances using state-of-the-art technology. It can help a client assemble and make products with near-perfect precision by securing supplies from Penang to Peoria in the most reliable and cost-effective way. It does so by squeezing unnecessary mass out of expensive inventories. Essentially there are no inventories. (p. 21)

It is important to note a critical factor in technologist behavior. The prepared mind of the technologist goes beyond the discovery of *what is*, as is the characteristic of many of the other sciences. The prepared mind of the technologist uses the intellect to imagine *what can be* and then *creates it*.

It is also important to note that the intellectual endeavors in the technologies are representative of the essence of what it means to be human. These endeavors, from early tool making to complex multination space endeavors, are at the core of our existential being.

I want to start over because of the exciting events taking place in the various technologies.

Developments in an Amazing Century

I often reflect on my father's life. He was born during the last decade of the 19th century in a coal mining community in southern Ohio.

Kent State University has officially reorganized the School of Technology and designated Dr. Aminur (Raj) Chowdhury its new Dean. The new organization empowers the former school, which was entirely campus based with nominal association with the associate degree and certificate programs at the University's seven branch campuses, to embrace all the technology programs in all the campuses under unified and articulated leadership.

Thomas J. Barber, Professor Emeritus of Technology and Dean Emeritus of Kent State University's College of Fine and Professional Arts and once Director of the School of Technology, played an instrumental role in conceptualizing and working toward the realization of the newly conceived organization.

A few years after he was born, an elementary particle, the electron, was discovered. The electron is an entity with the mass of one-thousandth or less of hydrogen, the lightest atom. This discovery was the precursor to many other wonderful events during his lifetime.

He witnessed the advent of powered, sustained, and controlled flight by the Wright brothers from Dayton, Ohio; the space flight of John Glenn, a future senator from New Concord, Ohio; the advent of commercial radio and television; atomic energy; the transistor and portable radios; the beginning of the computer age with ENIAC at the University of Pennsylvania in 1946; the birth and extensive use of radar in WWII; the advent of the "jet" age with the De Havilland Comet in 1952 and the Boeing 707 in 1958—each enabled by Frank Whittle's turbine engine; the lunar landing; the laser; antibiotics; direct blood transfusion; the Geiger counter; and medical diagnostic tools using computerized imaging and magnetic resonance. Each of these new tools has changed our lives in very significant ways.

But the length of our list does not matter. The important thing to remember is that none of these inventions, innovations, or developments had prior existence in nature. They did not grow on trees. They are manifestations of the human intellect.

Why do I want to start over? I'll give you a reason from the year 1947. This was the year the solid state century began. This was the year that three individuals, Walter Brattain, John Bardeen, and William Shockley, created the transistor. The transistor was followed some 11 years later by the work of Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor. They created the integrated circuit and changed our future forever. The integrated circuit was a critical enabling breakthrough. Without the integrated circuit, we would not have the personal computer and many other electronic devices that are so familiar to each of us here this evening. Why? Because the integrated circuit solved a problem known at that time as *the tyranny of numbers*.

The phrase *tyranny of numbers* was used to describe problems associated with creating a circuit of 100,000 components. A circuit of this size required over a million different connections. The only way to solder the connections was by human hand, a highly laborious, time-consuming, costly, and error-prone task.

Kilby and Noyce solved the problem by inventing a monolithic integrated circuit composed of millions of transistors and 100,000 or more circuits. We know these units as semiconductor chips. They are at the heart of our

computer systems.

However, the problem was not solved completely, even with the creation of the integrated circuit. Why? Because no high volume manufacturing system existed to produce these highly complex devices.

The major challenge of the solid state century was to design highly precise, highly reliable manufacturing systems. It was a particularly difficult assignment. The systems had to be designed to produce hundreds of thousands of semiconductors, each containing millions of circuits. The standards of precision, reliability, and defect tolerance were higher than any attained previously. And these standards were required when the unit being manufactured was smaller than an average postage stamp. The design of these manufacturing systems enabled us to enter the microelectronics era.

These new manufacturing systems did not appear magically. The systems designed to meet these requirements were the intellectual creations of manufacturing engineers and their prepared and educated minds. But the creation of these systems is another story, and far too complex to discuss here.

Correcting to Erroneous Views of Technology

I have found it interesting, however, that most educationists believe that these wonderful devices, which they use so willingly, will always appear somehow, as if by magic. They seem to believe that the technical devices that surround them are just a part of the natural scheme of things.

What do I mean by educationists? I use this term to differentiate among members of the education establishment. Some are educators, like my cousin Barbara who is here this evening. Some are educationists. There is a difference. To further inform you as to what I mean, I refer to Peter Drucker. He remarked some years ago that educationists are those who make a course a required course long after the subject has become totally obsolete.

Educationists are also the same people who spell technology C-O-M-P-U-T-E-R. They are also the same people who believe that all computers have a monitor and keyboard attached. They also believe that if there are computers in a classroom that the problem of students attaining technological literacy has been solved.

Some educationists with whom I have worked have stated in amazement and with great enthusiasm, "Look at all the technology out there." They perceive technology as being only the material aspects of a society. So, what

is technology if it isn't just a device or a thing out there?

Behavior of Technical Elements

I suggest that technology is the manifestation of a high order of insight and creativity. It is the result of many "acts of insight." These many creative acts of insight are what have enabled we humans to transcend the limits of our biological being in the realms of space, time, and distance.

But beyond this, it is critical to understand that the essence of the intellectual efforts in the technologies is understanding behavior. The goal of the technologist is to determine and understand the behavior of technical elements, devices, components, and systems. The questions of the technologist are about why and how things behave the way they do. The goal is control and predictability.

It is a focus that is central to all sciences, particularly the technological sciences. And it is the technological sciences that form the discipline base for the study and research pursued by the faculty and students of the School of Technology here at Kent State University.

The Central Role of Knowledge of Behavior

Why is the knowledge of behavior so central? There is one primary reason. Predictive capability enables a technologist to forecast the performance and reliability of the element, component, or system being designed prior to its being produced.

The first Lear jet, a very successful aircraft designed by Bill Lear, was built and flown without a prototype being built. The production version was the prototype. This was predictability in action. This was possible because Bill Lear and his engineers understood the behavior of structures in fluids. They understood the aerodynamics.

Today, a vast array of aeronautical knowledge is available to designers at their computer workstations. Today, mathematical modeling and simulation, by use of design software and computers, have enabled the design of entire aircraft without any paper drawings. An example is the Boeing 777. It was produced using over 130,000 electronic drawings.

The Wright brothers of Dayton, Ohio, are an early example of this focus on understanding behavior in the technological realm. They performed over one thousand glider flights at Kitty Hawk, North Carolina, to solve the problems of lift and control before they moved to the stage of powered flight. Their goal was to gain the understanding they needed to design the world's first aircraft that would meet the

criteria of powered, controlled, and sustained flight.

Those involved in the aviation programs here at Kent State University deal with the behavior of systems, including weather systems, so critical to flight safety. They are concerned about predictability. They fly by the numbers and can predict aircraft performance with considerable accuracy. Boundary layer control, laminar flow airfoils, and complex weight and balance calculations are a part of the domain of their behavioral knowledge.

The behavioral knowledge about which I am speaking is absolutely essential to the technological design process. If you cannot predict the outcome or performance of the element, device, component, or system being designed, then you cannot design a product that will meet required performance and reliability goals. Meeting performance and reliability goals is the primary criteria for ethical and successful commercialization. This is the reason the prepared mind, the receptive mind, is so central to the design process.

Often, as we pursue new frontiers in the technologies, the behavior of a given phenomenon is not known. Predictability is not possible. When predictability is not possible, then it becomes necessary to pursue research and investigation to determine the behavior of the particular element, component, device, or system in question.

A wonderful example of behavioral research in the technological sciences is documented in the March 1998 issue of *Discover*. The article concerns the research of Peter Wills at Stanford University. His focus is on the manufacture of machines 60 microns in diameter—this is 60 millionths of a meter or .002 inches, less than the width of a human hair. A functioning electric motor was built to this dimension in 1988.

Peter Wills is involved in research focusing on the design of means to manufacture these machines en masse. The question he is pursuing is how can one assemble, on a mass production basis, the various parts of a machine when the total machine is .002 inches in diameter or smaller? Certainly, as was discovered early in the effort, not with tweezers, a microscope, and the human hand.

Visualize with me for a moment as I describe how Wills is approaching the problem. He is exploring the possibility of using a flat table. The table will have a surface composed of thousands of cilia, extremely small hair-like elements such as those in the human lung. His idea came from the human lung.

Remember the importance of the prepared mind. In Wills' vision of the solution, a com-

puter program will direct each cilium. The cilia, working as a team, will be programmed to push, lift, or turn a small part. Willis is attempting to determine the behavior of cilia and each of the elements and components of the total system. The goal is to be able to design reliable manufacturing systems for the high volume manufacture of micro electromechanical systems (MESs).

Exciting Positive Consequences from Collective Human Action and Accepting Limits

I want to start over because by focusing on the behavior of systems, we have the potential to create technologies that are compatible with the life-giving and life-sustaining natural environment. The concept of bioregionalism—each region of the Earth is unique—and the concept of sustainability provide us with insights into probable solutions to the problems we have created by inappropriately designed or inappropriately used technologies.

Fortunately, the realization is growing that everything is connected to everything else. We now have the opportunity to design technological systems that are compatible with natural systems, and not exploitative of them. This discovery and realization gives us hope that sustainability of a high quality life and the advancement of civilization are not incompatible.

Everyone here this evening can cite many examples of environmental and social disasters brought about by the creation and use of inappropriate technical means. Many years ago there were early warnings from this area.

I recall the time three Case Western Reserve students rowed their boat past the Glidden Paint factory on the Cuyahoga River in Cleveland. One student stuck his arm into the water. When he withdrew his arm it was coated heavily with green paint. The paint had been dumped recently by the Glidden Paint factory. Glidden's disposal facility was the Cuyahoga River. Most of you will recall that this same river caught fire some years later.

It wasn't too many years ago that Lake Erie was declared a dead lake. The indiscriminate dumping of sewage and industrial wastes by communities and industries lining the shores of Lake Erie, on both the U.S. and Canada sides, destroyed the commercial fishing industry. This became an economic disaster to thousands of people who earned their living from fishing. And we talk about economic development and jobs.

Certainly, those who were responsible for the dumping did not consciously design a program for the destruction of Lake Erie. Rather, the problem occurred because of a phenom-

enon known as collective human action. What is collective human action? By way of example, let me cite Lake Erie again. One industry dumping into Lake Erie may do little harm unless, of course, the substance is mercury, asbestos fibers, or other toxic substances in large quantities.

However, the individual decisions of thousands of industries and communities to dump into Lake Erie became an unmitigated disaster. We don't plan these disasters. They happen because of our individual human actions. Each individual action becomes part of a collective result. These disasters brought about by collective human action also happen because of our limited knowledge about the relation between our actions and the consequences of our actions.

Another example is the continuing disaster of the Chesapeake Bay, the breeding ground for the aquatic life of the Atlantic. So is the demise of the Grand Banks fishing industry, the result of over fishing. The outcomes of the results of collective human actions have been significant economic losses to the fishing communities in Canada and the United States. Entire communities have been devastated by the destruction of the fisheries. And we talk about jobs and economic development!

We know now that there are consequences to our actions. We know now that there are limits in the ability of the natural environment to accept continual abuses by humans and their powerful, but inappropriate, technologies.

We must ask ourselves, What will be our legacy? My answer is, That depends. It depends on whether we are willing to accept that there are limits in the ability of our natural systems to absorb continually the results of the inappropriate activities and wastes of humans. It will also depend on whether we are willing to design and redesign our technological systems so they are compatible with the natural environment, and not exploitative of it.

The Challenge

Why do I raise the issue of the nature of our technological systems in relation to the life-giving and life-sustaining earth? I raise the issue because I believe this issue will affect directly the mission of the reorganized School of Technology.

It may be that the Vision 21 Challenge of this School, and this University, will be to build a foundation of technological study and research from which to address one of the most challenging issues of our society, sustainability.

Should the faculty and students in the School of Technology be willing to accept the chal-

From my experience, I can assure you that people do not want to hear about limits. Let me give you an example. Dr. Chowdhury, your Dean, has been searching for some years for answers to a philosophical question. He inquired, after his arrival here in Ohio, if there were any insightful individuals of great wisdom in the area. He was informed about a well-respected guru that lived in Vinton County in a hillside enclave.

So one weekend Raj visited the guru. He asked the guru the question that had been plaguing him for some time. "What are the keys to happiness?" The guru, without hesitation replied, "Follow a low fat diet, exercise every day, and practice abstinence and celibacy." Raj recovered quickly from the impact of this reply and said, "Is there someone else up here that I can talk to?" So you see, even deans are not willing to accept limits. (Adapted from Hagar the Horrible by Dik Browne) PWD

lenge of contributing to designing this foundation, their contribution to society can be immense. They will discover, however, that when they pursue this effort they will need to become knowledgeable in areas far beyond the operation of technical devices and systems. They will find that they must direct their efforts to the heart of the issue. The heart of the issue involves assessing, designing, and redesigning the very technological foundation of our society. The goal will be to design systems that are compatible with nature, rather than exploitative and destructive of nature and human life.

I want to start over because I believe it is possible to use the knowledge of this foundation and the answers to the eternal questions of all time to create a better future for humankind. I believe the equation for success contains both technological and human factors.

I believe that if we are to create a better future, we must begin first by revisiting the fundamental questions asked by humans over the centuries. Who are we? Why are we here? Where are we going, and why? And lastly, How will we get there?

I bring these questions forth for your consideration here this evening for one reason. I believe it is important to remember always that the study of technology is a very human endeavor. The study of technology encompasses not only the study of the creative power of the human mind in bringing forth technological systems, it also focuses on the essence

of what it means to be human.

Thus, our concern must be on how technological systems can be designed and redesigned to enable each human to attain his or her fullest potential and to create a better society for all.

And our concerns can be directed best by focusing on the behavior of systems, connectedness, the consequences of our collective human actions, the concept of limits, bioregionalism, and the sustainability of our natural and technological systems.

I submit that these are necessary elements for the faculty of the School of Technology at Kent State University—faculty everywhere—to consider. They are necessary if you believe that your Vision 21 Mission is to provide quality, well-grounded leadership in technology studies for this region, this state, and our nation.

The prepared mind, the educated mind, is central to attaining this goal. This is why the mission of schools of technology is so critical. The prepared mind and the educated mind will enable the graduates to continue learning long after completing their basic education at this and other universities.

I make this point because each of us is always in the process of becoming. We are always at the point of a new beginning, of starting over, whether we want to or not. This is the nature of life.

And now you know why I want to start over.

Reference

Garent, J. (1998, March 23). Why the global economy is here to stay. *Business Week*, p. 26.

2. Issues in Defining Goals in Technology Education

There has been a tendency over the last three or four decades to justify the place of technology education within our schools by stressing the *intellectual* value of the work over its more easily identifiable *practical* virtues. This tendency has arisen partially from what is seen as an opportunity to enhance the subject's image, but it is also as a result of a genuine concern that through a practical and process-driven approach, students will not only be able to acquire technological understanding but also a wide range of generic life skills.

This article, however, suggests that while the process approach to technology education is valuable, its results are not always satisfac-

tory. This is due to a number of reasons:

1. The difficulty in understanding an abstract philosophical justification for an apparently *practical* subject.
2. Difficulties with implementing a suitable pedagogy.
3. Difficulties in understanding the value and relationships between the *cognitive* components or elements of the problem-solving model.
4. The problems posed by evaluating a *process* model through a *project* using a theoretically *objective* strategy which in practice is highly subjective.

Since the mid 1960s, educationalists have developed a number of models that are said to

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illustrate what has become known as the problem-solving approach within technology education. For example, work published recently within the United States (International Technology Education Association, 1996) has produced a model of technology constructed from what are termed the three *universals*. These are *processes, knowledge, and contexts*. As used in this model, *processes* is a broader concept than that understood within the United Kingdom, although it does include *designing and developing technological systems* as one of four components. While the designing and creative activity of the U.S. model is seen as making a significant contribution to technological literacy, it does not appear, at this stage in the debate, to hold the central position that design and creative activity does in the United Kingdom.

The models of technology vary in their complexity. However, they all attempt to illustrate a logical or step-by-step approach to designing, breaking each step down to specific activities such as research, generating ideas, and evaluation. They can be simple, linear algorithms or the more complex models which attempt to accommodate the nuances that are evident in professional practice (Kimbell, Stables, Wheeler, Wosniak, & Kelly, 1991).

The problem-solving strategies in current thought on technology education stem from at least three sources. The first and most frequently quoted by technology teachers is that technology is not a collection of facts but a process through which technologists solve problems by applying scientific and other knowledge. The second and perhaps most attractive to the curriculum specialist is that general problem-solving abilities are an essential component of the life skills of an educated person. The third understanding links doing with learning. In other words, by involving children in practical activity they are enhancing their cognitive abilities.

Obviously, a wide range of practice is covered under this simplistic classification. For example, there will be some who very systematically ensure (often through a didactic approach) a thorough understanding of scientific and other knowledge and skills that are integral to the technology process while they strongly advocate a process approach.

However, it is important for all teachers to reach an understanding of where the subject is coming from. If they do not understand the different philosophical and educational objectives, there is confusion that leads to a lack of definition in learning objectives and also teaching and learning strategies (Medway,

1989). This leads to unsatisfactory levels of attainment in their students.

Add to this sort of confusion the understandable desire of teachers and students to meet the requirements of the assessment strategies being employed, and the resultant efforts to "teach to the examination," and the issues become further confused. This lack of focus may be one factor behind some of the problems that have emerged in our schools when teachers have attempted to employ process-driven approaches in the classroom (McCormick & Davidson, 1996; Shield, 1996b; Underbakke, Borg, & Peterson, 1993).

Philosophical and educational objectives are not easy to implement (Shield, 1996a). The interaction between process, content, and assessment in technology education is complex and all aspects are mutually dependent. They rely upon each other for the design and manufacture of products and artifacts and, consequently, in the development of technological understanding within our students.

Because designing depends to a large extent upon the knowledge and skill base of the designer (Glaser, 1993), it appears sensible that in teaching how to design, teachers should ensure a structured input of relevant concepts so that students are not working in vacuo. Black and Harrison (1990) emphasized the need to understand this relationship between what they term *resources* and what are called *tasks* in technology education. This modification of a content-free process approach to technology education is outlined in the National Curriculum of England and Wales (Department of Education, 1995). This reflects emerging trends that signify a drift from the more abstract, and some would say the more fundamentally valuable, objectives of enhancing general transferable process skills and understanding to objectives that can be more readily observed and measured.

How and Why Is This Happening?

Teaching how to design, within a technology context, is often initiated by describing and then dividing the whole process into subunits such as the brief, research, analysis, and evaluation. Children are then given instructions on how to interpret such concepts.

The results of such an approach are often trivial and lacking in quality of thought or execution. Kimbell, Stables, and Green, (1996) recognized these drawbacks and outlined activities that can be employed by teachers to guide children to employ tactics and strategies to address what are apparently key components of designing and making activities. This strategy, while valuable, is insufficient be-

cause children need guidance not only about how to manage the activities but also fundamental clarification of the concepts themselves. In other words, the logical, in most cases sequential, strategy of approaching a problem through “breaking down the whole” into what appear to be more manageable parts may not be effective on its own. This strategy sidesteps a key requirement of teaching designing, that is, it is the perceptual skills of the students that are important and not solely the ability to carry out a logical process (de Bono, 1995).

Perceptual skills, however, are difficult to both identify and enhance. Perceptual skills in this context are taken to be the ability to identify aspects of a problem that may be resolved by either applying solutions gained by extrapolation from novel situations or by disassembling existing solutions, gaining the insights necessary to design the modification, usually from widely disparate sources, and then have the know-how to make the modifications feasible. This activity may be the foundation of most of the subprocesses identified in many of the process models in use.

This understanding is not surprising. Most teachers realize the need to demonstrate and then devise opportunities for practice for skills in the psychomotor domain before children engage in them, but such attention to detail in the cognitive process of designing is not so obvious. If the highly structured approach to a practical process is contrasted with what occurs when a teacher tries to engage children with the design process, the directions given are often more vague.

These pedagogical issues are being increasingly identified as having a bearing upon our work and they require clarification. However, it is the pressure from the ubiquitous process model that appears to be driving our subject forward, and therefore, it is this aspect that needs understanding and possibly refinement as a priority.

Johnsey (1995) analyzed a number of process models and listed areas common to them. This work has been used here in an attempt to produce some consensus of the terms used. To further this analysis, the work of teachers and others has been examined to see what they consider are the salient features in each of the elements of process and how they attempt to enhance them. This list is not a model of a process in itself, but more of an explication of existing algorithms (see Table 1). Indeed, listing these “steps” may be a disservice to designing as an understanding of the “wholeness” of what takes place may not be helped. It may, however, be viewed as an interest-raising interim measure on the way to gaining

an insight into the learning process undertaken by students when they are engaged in designing activities.

Under the *Element* category a number of activities have been listed and are featured in one or more of the various process models in use. Some of the terms are interchangeable, or at least close in definition, and they try to indicate specific subprocesses or stages in process models in use.

Description is an attempt at elaborating on these terms to tease out more detail of what is required so that the teacher and learner can focus on the results of the activities. By trying to describe the nature of the “higher order” generic activity or skills that are said to be enhanced by these activities under the title of *descriptor of activity/skills*, some behavioral objectives in the cognitive (mainly) realm that can be claimed as resulting from following the activities are indicated. This list is not definitive; it only elaborates on key factors in the process of designing. And finally, by describing some of the *teaching and learning strategies* that are employed, the descriptor can be further clarified.

In an exercise such as this, individual interpretations often color not only the concepts under discussion, but also the teaching and learning strategies to be employed. Nevertheless, only when such understandings begin to be articulated and discussed can progress be made towards making the bridge between a valuable education theory and the practical difficulties faced by teachers in their attempt at implementing it.

Two points are immediately obvious from such a scrutiny. The first is that similar core skills/activities are being fostered in a number of stages of the model. This by itself may not be a problem because repeating learning objectives through different contexts and by using different strategies may simply serve to clarify and build upon existing knowledge. It may also indicate a need to be aware of such replication and, consequently, to develop progression within the task or unit of learning and to recognize this within its evaluation.

The second point is that nearly all of the activities require a knowledge base to carry them out. In other words, it is impossible to judge, evaluate, and comprehend without a context within which to work. One has to have criteria to judge and evaluate, and a framework within which to comprehend an issue.

Initially we must be involved in attempts to develop an understanding of what takes place in the area of the cognitive domain when we are addressing specific design subprocesses and then establish what is required to enable

Table 1

An Explication of Terms Common to Technology Education Algorithms

Element	Description	Descriptor of Activity/Skills	Teaching and Learning Strategy
Identifying	This normally refers to the "problem" to be solved, the "needs" of an individual or group, or the "market."	Comprehension	Possibly the most difficult part of the process. Standard methods of teaching include establishing a context through visits, or stimulus material (e.g., books, video, visiting experts). Many teachers give a brief which covers their own agenda in terms of content. Motivation is a very important component of design activity, and teachers concentrate on fostering it.
Clarifying	What is required here is the tighter specification of the problem. It relies on analytical skills and knowledge of processes and materials.	Knowledge of materials and processes Analysis	Normally carried out in discussion with client. Children need to be taught both to listen carefully for what is required and also "what to look for." This requires an input of information about "what is possible" and not only what is desirable.
Specifying	It is at this point that the clarification can be documented through ordering and structuring initial requirements.	Comprehension Summarizing	Normally the requirement can be listed in words rather than sketches, which tend to preempt a solution. The structured enhancement of language skills is important if concepts are to be developed.
Researching	A loosely defined operation in which relevant information and data is gathered and assembled for later use.	Analysis Discrimination	Basic information on how to access databases, indexes, and catalogues is essential. Time must be spent on teaching how to pursue a lead through published material. Other techniques, such as how to conduct market surveys, should also be included. While this can be time consuming, it is assumed that much can be achieved through "structured work sheets" and also that it is a linear skill which can be consolidated, over time, with increasing degrees of sophistication.
Generating	Initial ideas are now synthesized and thoughts shown on paper (or in other media).	Ability to synthesize Rearranges ideas and information	A wider range of communication skills must be taught alongside techniques for "lateral thinking." Brainstorming, examining existing solutions, using source material. Individual work with a teacher "drawing out" from the child possible solutions is highly desirable for high levels of success. Small groups of "equals" engaged in discussion not only help to sort out ideas but also to "internalize" some of the new concepts. The use of drawing will appear here, and throughout the whole designing and making process, as a medium not only to communicate ideas between people but also as a learning method to develop cognitive processes.
Selecting	This term indicates a strategy of selection from alternative solutions, choosing the best, selecting the optimum, and explaining and developing ideas.	The application of prior knowledge	Pupils will need to know about optimum solutions (i.e., bearing in mind production techniques, economics, etc.). Other input will include information about properties of materials. Again while it is appropriate to formally teach some of the essential information, much can be learned from a resource base and a directed program of individualized learning.
Production of working drawings	The nature of the drawings is determined by the product. Formal working drawings may be required in some situations while in other cases different techniques may be employed.	Analysis Development of psycho-motor skills Communication skills Illustrates	As with making skills, it is probably more effective at some stage to teach the basics of drawing in a formal teaching situation. The specific requirements of individual children may be covered either by learning packages or through one-to-one interaction. The use of CAD packages requires a different set of skills but possibly a similar conceptual understanding
Modelling	By developing and testing ideas through manipulating materials and also by producing simulations, solutions can be reached in a quicker, more efficient manner.	Communication testing Discrimination	Modelling can be effective but often includes a wide range of special techniques and materials that do not reflect finished product. Scale is important. The use of IT is particularly valuable in the trailing and modification of ideas.

Planning	The manufacturing process is defined and planned, intentions are detailed and strategies proposed.	Organization Synthesizing	With the enhancement of the child's knowledge, a priority input must be given not only on what is possible but also time planning and the efficient use of available resources.
Making	The manufacturing process is implemented by using tools and instruments. The solutions may be modified as manufacturing proceeds.	Skills of adaptation	Due to the spread of progress within the group, it may be useful to use small group demonstrations of new skills and techniques. This allows more time for helping individual children. While essential safety factors are best taught to whole groups, it is important to bear in mind that learning is more effective when the processes are relevant to the task in hand.
Testing	An assessment is made of the effectiveness of the solution. Tests are carried out and judgements validated.	Comparing Judging	These tests may be quantifiable (e.g., the product may have to be a specific size or carry a specified load) or based on subjective opinion which can be articulated. The concept of "quality control" may be introduced here and discussed as a whole group activity.
Modifying	Alterations are carried out in the light of the tests carried out, adjustments made if possible.	Evaluation Interpretation	Again alterations must be carried out bearing in mind available resources, the advantages gained, and the cost of the changes. This is a high-level activity that may require individual input.
Evaluating	Judgements made of the solution in terms of the brief and specification. It involves a critical appraisal of the outcomes.	Judging	The critical appraisal must be based upon informed opinion. This may demand inputs on how to accept criticism, as well as about alternative products. Again discussions of quality and what it means in the context of the market are useful.
Report writing	In this context the report is normally an account of the project used as a learning strategy. It may however also be used as part of the consultation process with the client.	Synthesizing Summarizing Justifying	Specific writing skills should be taught. The need for precision and economy without terseness should be identified (Potter, 1980).

us to see if our students understand this complex process. In other words, what needs to be done to ensure that progression is built into the system? How do we enhance the skills of selecting the optimum solution from a number of tentative options? And how do we then go on to evaluate the student's ability?

In practice the assessment of objectives in a design process relies heavily upon the subjective opinion of assessors, which is frequently cloaked by attempts at an objective (quantifiable) justification of their views. Table 2, taken from a General Certificate of Secondary Education (GCSE) marking schedule, is an example of this.

It is apparent that the descriptors used to guide examiners and teachers are wide open to a range of subjective interpretations: What is meant by a "low standard of communication techniques," "a cursory evaluation," "several solutions," "a range of appropriate solutions," and "one or more?"

If this process is analyzed more precisely, a number of steps in the evaluation of a student's technological understanding from work produced using a process model are revealed to lack precision.

1. The examiner (evaluator) attempts to ver-

balize the information to be gained by posing the test questions based upon experience.

2. The student then attempts to interpret the question (i.e., just what does the examiner want?).
3. The examiner then attempts to define *standard* in terms of descriptors to guide both teachers and markers.
4. The markers then have to apply these criteria using their understanding of what is meant by the descriptive terms used.
5. The marker has to decide a point within the suggested range and allocate a mark.
6. The marks are then totaled and a grade from within a scale (from A-E with U for unclassified) allocated.
7. Frequently these grades are then subjected to a moderation exercise by other experts.
8. Finally the user (student, parent, employer, etc.) of the exam result has to reinterpret the allocated grade to get a picture of what such a grade represents to establish the student's capability.

At the end of the day, the accuracy of such judgments are highly dependent upon the effectiveness of the process of inducting assessors into a community of professionals and the

Table 2

Extract From GCSE Marking Schedule

Design and Technology Coursework Assessment 3		
Objective 3: Generation of Design Solutions	Level of Response	Mark Range
Candidates will need to: <ul style="list-style-type: none"> • generate a range of design solutions • evaluate their design solutions against the specification • consider whether their ideas meet the need and its fitness for purpose • identify chosen design proposal for product development • present design solutions using a combination of text, graphical techniques, and computer generated images and/or three dimensional models NB the balance between these methods of presentation may differ depending upon the focus area of design and technology study.	One or more solutions proposed. Little or no evaluation. The work presented displays a low standard of communication techniques	0–3
	Several solutions proposed. A cursory evaluation. Unsupported choice of design proposal. Communication will be of a reasonable standard using a limited number of techniques.	4–6
	A range of appropriate solutions proposed. Design proposal chosen, supported by clear evaluation. Communication will be a good standard, well presented using a range of appropriate techniques.	7–10
	A wide range of appropriate solutions proposed. Design proposal chosen as a result of detailed evaluation and consideration of the need and fitness for purpose. Communication will be a high quality, well presented and using a wide range of appropriate techniques.	11–14
Total		14

continual reinforcement of a common understanding and only peripherally to any objective criteria.

In view of these considerations, a teacher's first step in evaluating a student's understanding of design would appear to be to judge all of the solutions produced against established criteria. This presupposes that our pupils have sufficient knowledge of the materials, processes, and technological principles to enable them to implement a solution in the first place (i.e., the understanding that such a process needs to be done does not necessarily equip students to carry out this task). The value of such an instrument for formative or summative assessment would therefore depend upon a refined approach using more and more detailed criteria. But more does not necessarily mean a deeper understanding (in fact, it could result in a wide, shallow exercise) or rely on more subject (content) knowledge. This does

not appear to be an adequate way forward.

Kimbell et al. (1991) looked very closely at aspects of assessment and provided some indicators for the way ahead. Some of the issues raised earlier, however, are still apparent and still appear problematic. For example, in designing a toy they reported, "We found low-level evidence of justification, e.g. 'its good because its red,' as well as more sophisticated examples, e.g. 'good because the baby could still use it as it gets older'" (p. 163).

This example is interesting because it illustrates what may be termed higher level thinking. It still leaves the issue of progression open to discussion. How could a teacher plan for progression, to move from one level to another?

In the first example, it may be said that the child is merely stating a preference without any reasoning to back it up. In the second example, however, it could be said that the

child has a knowledge of child development to inform the response—but if this was so, how was the knowledge acquired? Was it a result of a structured program in a school or has the child tapped into background knowledge gained from family life. If it is the former, how is such a program devised by a teacher bearing in mind the extensive nature of technology? If it is the latter, how do we teach children to make these jumps from unconnected sources, other than merely providing opportunities to express them?

Schwaller (1995) produced a model that indicates a hierarchical structure to the process of problem solving or designing. While this theory is generally accepted and has been found to be of value in some aspects of education, the complexity of technology problem solving and the interdependence of these many subprocesses causes us to question its merit as a tool upon which to base an assessment strategy or indicator of progression. It does indicate an understanding that could be used to devise strategies of teaching/learning that can be used in the classroom. It also indicates the danger of confusing models of technology with theories of learning, despite their superficial similarities.

In a praiseworthy attempt to clarify standards and achieve consistency in assessment, the Schools Curriculum and Assessment Authority (SCAA) has produced guidelines for teachers (SCAA, 1996b) as well as optional tasks and tests (SCAA, 1996a) that can be used to aid understanding of the requirements of the National Curriculum (NC). While the tasks and tests are considerable improvements on earlier thinking, since they identify key features of specific design and make activities together with an understanding of technologi-

cal principles, the results of the process (e.g., the measuring of students' performance) is dependent upon teachers' subjective interpretation of the given descriptors.

Where To From Here?

A sound knowledge base to underpin any process strategy is becoming increasingly evident and is comparatively easy to assess. But it is not sufficient. Students must be taught how to rearrange and interrelate information, and this ability must be evaluated if the assessment is said to measure higher order thinking.

One view, which may be considered heretical in its implication, is that while we still emphasize the value of an understanding of the logical and systematic process of designing as a part of training in transferable skills, we must also recognize that not all elements of education can be assessed. It may be sufficient that the final product of the design or technology exercise is evaluated against the initial brief accompanied by a summary report. Assessment instruments that do not rely upon project work can then be used to test skills such as time management, writing a brief, and planning a project if this is judged necessary.

To ensure that the designing or making element within technology education is retained as an essential component, it may be necessary to revise both our teaching strategies and assessment practice. If the value of a process model is to be substantiated, it would indicate that progression within it can only be pursued through enhancing subject knowledge and skills while demanding that they be used in the context of a logical problem-solving approach. This view weakens the case of those who present content-free strategies of technology education to develop the concept

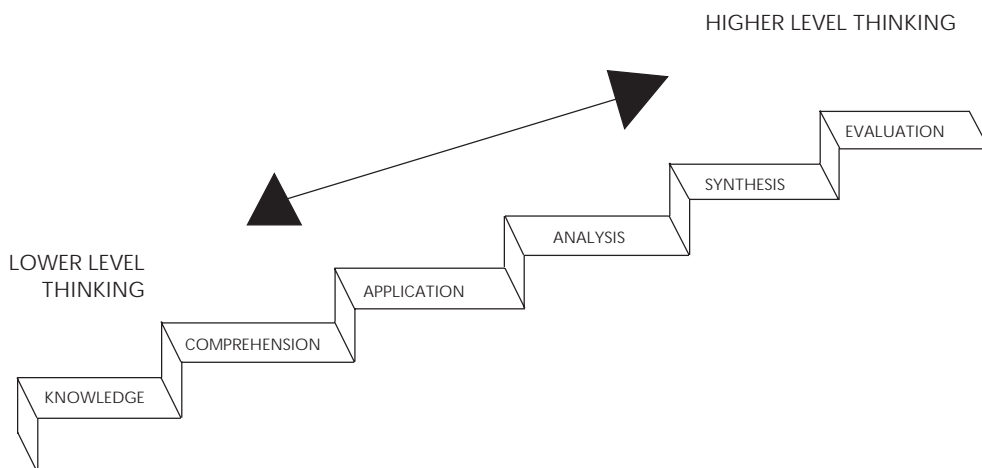


Figure 1. The six stages of learning in the cognitive domain (Schwaller, 1995).

of generic or generalized transferable skills. And it may also go further and help to substantiate the opinions of those who say that designing can only be taught within the parameters of a specific discipline, such as product design, engineering, architecture, or any other technology.

It may also be more indicative of a lack of

focus on teaching higher order thinking skills within our current technology education learning environment, brought about not through an inability of teachers, but through an inappropriate understanding of the nature of the technology process and unsuitable assessment instruments.

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