Creativity and Design in Technology & Engineering Education

Editors

Scott A. Warner
Perry R. Gemmill

60th Yearbook, 2011

Council on Technology Teacher Education

CTTE

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1914 Association Drive
Suite 201
Reston, VA 20191-1539

ISBN-13: 978-1-887101-10-3

Printed in the United States of America.

1 2 3 4 5 6 7 8 9 10   044   11 10 09 08 07

This publication is available in microfilm from:
UMI
300 North Zeeb Road
Dept. P.R.
Ann Arbor, MI 48106

FOREWORD

Creativity is a great motivator because it makes people interested in what they are doing. Creativity gives hope that there can be a worthwhile idea. Creativity gives the possibility of some sort of achievement to everyone. Creativity makes life more fun and more interesting. Edward de Bono

The annual Council on Technology Teacher Education (CTTE) yearbook series showcases important happenings and trends in the field of technology education. Each yearbook is written by professionals who are passionate about advancing knowledge, research, and skills in the field of technology education and the emerging field of K-12 engineering education. This tradition of excellence continues and the CTTE is proud to present its 60th yearbook that focuses on concepts related to *Creativity and Design in Technology & Engineering Education*.

Creativity and design are important in technology education. Creativity involves “thinking outside the box” and it helps to foster many of today’s new innovations and inventions. Design is a problem solving process and often requires using creative thinking to help solve problems and extend human capabilities. This yearbook provides an in-depth review of creativity and design in technology education and explores many important related concepts.

The 60th yearbook begins by setting the context for creativity and design in technology education and defines their meaning. The first section of chapters focuses on creativity. They examine the many forms of creativity. The second section of chapters focuses on concepts related to the developmental stages of humans and creativity, the human brain as the source of creativity, as well as creativity, innovation, and design thinking. The third section of chapters examines pedagogy and environments for creativity and design; specifically, matters related to knowledge and skills as well as the physical and cultural environments for creativity and design are discussed. This section also focuses on the importance of developing curriculum, instruction, and assessment for creativity and design. The final section of the yearbook looks at the importance of professional development. The yearbook concludes with a conceptual model and future perspectives for using and enhancing creativity and design within technology and engineering education.

The editors, Drs. Scott Warner and Perry Gemmill, and their chapter authors have worked diligently in developing this timely publication and should be commended for their efforts. I would be remiss if I did not call special attention to one of the authors, Gerald F. Day, who passed away shortly after completing his chapter. He was a consummate professional in the field of technology education.

On behalf of the Council and the Yearbook Committee, we are honored to present this publication to the profession. I know you will enjoy reading and learning about the many aspects related to creativity and design in technology education and its importance to developing dynamic and progressive technology and engineering education curricula.

Edward M. Reeve
President, CTTE
June 2011

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YEARBOOK PROPOSALS

Each year at the ITEEA International Conference, the CTTE Yearbook Committee reviews the progress of yearbooks in preparation and evaluates proposals for additional yearbooks. Any member is welcome to submit a yearbook proposal, which should be written in sufficient detail for the committee to be able to understand the proposed substance and format. Fifteen copies of the proposal should be sent to the committee chairperson by February 1 of the year in which the conference is held. Below are the criteria employed by the committee in making yearbook selections.

CTTE Yearbook Committee

CTTE Yearbook Guidelines

A. Purpose

The CTTE Yearbook Series is intended as a vehicle for communicating major topics or issues related to technology teacher education in a structured, formal series that does not duplicate commercial textbook publishing activities.

B. Yearbook topic selection criteria

An appropriate yearbook topic should:

1. Make a direct contribution to the understanding and improvement of technology teacher education;
2. Add to the accumulated body of knowledge of technology teacher education and to the field of technology education;
3. Not duplicate publishing activities of other professional groups;
4. Provide a balanced view of the theme and not promote a single individual's or institution's philosophy or practices;
5. Actively seek to upgrade and modernize professional practice in technology teacher education; and,
6. Lend itself to team authorship as opposed to single authorship.

Proper yearbook themes related to technology teacher education may also be structured to:

1. Discuss and critique points of view that have gained a degree of acceptance by the profession;
2. Raise controversial questions in an effort to obtain a national hearing; and,
3. Consider and evaluate a variety of seemingly conflicting trends and statements emanating from several sources.

C. The Yearbook Proposal

1. The yearbook proposal should provide adequate detail for the Yearbook Committee to evaluate its merits.
2. The yearbook proposal includes the following elements:

a) Defines and describes the topic of the yearbook;
b) Identifies the theme and describes the rationale for the theme;
c) Identifies the need for the yearbook and the potential audience or audiences;
d) Explains how the yearbook will advance the technology teacher education profession and technology education in general;
e) Diagram symbolically the intent of the yearbook;
f) Provides an outline of the yearbook which includes:
    i) A table of contents;
    ii) A brief description of the content or purpose of each chapter;
    iii) At least a three level outline for each chapter;
    iv) Identification of chapter authors (s) and backup authors;
    v) An estimated number of pages for each yearbook chapter; and,
    vi) An estimated number of pages for the yearbook (not to exceed 250 pages).
    g) Provides a timeline for completing the yearbook.

It is understood that each author of a yearbook chapter will sign a CTTE Editor/Author Agreement and comply with the Agreement. Additional information on yearbook proposals is found on the CTTE web site at http://www.ctete.org/

PREVIOUSLY PUBLISHED YEARBOOKS

***1.** *Inventory Analysis of Industrial Arts Teacher Education Facilities, Personnel and Programs*, 1952.
***2.** *Who's Who in Industrial Arts Teacher Education*, 1953.
***3.** *Some Components of Current Leadership: Techniques of Selection and Guidance of Graduate Students; An Analysis of Textbook Emphases*; 1954, three studies.
***4.** *Superior Practices in Industrial Arts Teacher Education*, 1955.
***5.** *Problems and Issues in Industrial Arts Teacher Education*, 1956.
***6.** *A Sourcebook of Reading in Education for Use in Industrial Arts and Industrial Arts Teacher Education*, 1957.
***7.** *The Accreditation of Industrial Arts Teacher Education*, 1958.
***8.** *Planning Industrial Arts Facilities*, 1959. Ralph K. Nair, ed.
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***24.** *A Guide to the Planning of Industrial Arts Facilities*, 1975. D.E. Moon, ed.
***25.** *Future Alternatives for Industrial Arts*, 1976. Lee H. Smalley, ed.
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***31.** *The Contributions of Industrial Arts to Selected Areas of Education*, 1982. Donald Maley and Kendall N. Starkweather, eds.
***32.** *The Dynamics of Creative Leadership for Industrial Arts Education*, 1983. Robert E. Wenig and John I. Mathews, eds.
***33.** *Affective Learning in Industrial Arts*, 1984. Gerald L. Jennings, ed.

***34.** *Perceptual and Psychomotor Learning in Industrial Arts Education*, 1985. John M. Shemick, ed.

***35.** *Implementing Technology Education*, 1986. Ronald E. Jones and John R. Wright, eds.

***36.** *Conducting Technical Research*, 1987. Everett N. Israel and R. Thomas Wright, eds.

***37.** *Instructional Strategies for Technology Education*, 1988. William H. Kemp and Anthony E. Schwaller, eds.

***38.** *Technology Student Organizations*, 1989. M. Roger Betts and Arvid W. Van Dyke, eds.

***39.** *Communication in Technology Education*, 1990. Jane A. Liedtke, ed.

***40.** *Technological Literacy*, 1991. Michael J. Dyrenfurth and Michael R. Kozak, eds.

***41.** *Transportation in Technology Education*, 1992. John R. Wright and Stanley Komacek, eds.

***42.** *Manufacturing in Technology Education*, 1993. Richard D. Seymour and Ray L. Shackelford, eds.

***43.** *Construction in Technology Education*, 1994. Jack W. Wescott and Richard M. Henak, eds.

***44.** *Foundations of Technology Education*, 1995. G. Eugene Martin, ed.

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***49**. *Technology Education for the 21st Century: A Collection of Essays*, 2000. G. Eugene Martin, ed.

***50**. *Appropriate Technology for Sustainable Living*, 2001, Robert C. Wicklein.

51. *Standards for Technological Literacy: The Role of Teacher Education*, 2002. John M. Ritz, William E. Dugger, and Everett N. Israel, eds.

52. *Selecting Instructional Strategies for Technology Education*, 2003. Kurt R. Helgeson and Anthony E. Schwaller, eds.

53. *Ethics for Citizenship in a Technological World*, 2004. Roger B. Hill, ed.

54. *Distance and Distributed Learning Environments: Perspectives and Strategies*, 2005. William L. Havice and Pamela A. Havice, eds.

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56. *Assessment of Technology Education, 2007.* Marie C. Hoepfl and Michael R. Lindstrom, eds.

57. *Engineering and Technology Education, 2008.* Rodney L. Custer and Thomas L. Erekson, eds.

58. *Essential Topics for Technology Educators.* CTTE Yearbook Planning Committee, eds.

59. *Research in Technology Education, 2010.* Phil Reed and Jim LaPorte, eds.

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PREFACE

Creativity has been associated with the peak experiences in one's life. Giving birth to new ideas, relationships, and objects usually requires effort, perseverance, and know-how. Creative people are intrinsically motivated and rewarded with the joy that they receive from being engaged in design processes and the resultant outcomes.

Creativity and design has been a global fundamental theme of technology education for over a century. Its ebb and flow of focus as content and pedagogy have fluctuated as the educational philosophies, teacher expertise, and economy have changed. K-12 basic education and conventional standards-based assessment have been structured around convergent thinking and right answers. Yet, the complex issues and problems of today's advancing technological society often demand and reward critical examination, divergent thinking, and fresh, novel answers and solutions. The technological literacy and capability of educated citizens requires knowledge and skills of creative and designerly ways. The explicit identification of design themes and standards in *Standards for Technological Literacy* and the emergent focus on engineering design within our profession have reinforced the educational value of studying and practicing creativity and design in our schools. Creativity and design leading to innovation also has been recently promoted as the key to global economic competitiveness.

The editors and authors of this Yearbook represent a variety of backgrounds, including classroom teachers, teacher educators, and supervisors who represent not only technology education but also architecture, neurology, design, engineering, industrial technology, and art education and crafts. This diversity has reinforced and enriched the total educational value of this Yearbook toward promoting creativity and design.

We hope that the theory and perspectives presented in this Yearbook revitalize the pursuit of creativity and design within technology and engineering education. We believe that the precepts for teaching and learning the important concepts, principles, and practices embedded in creativity and design serve as an engaging catalyst for meaningful, productive, and fulfilling lives of all people in the 21st century.

60th Yearbook Editors
Scott A. Warner
Perry R. Gemmill

ACKNOWLEDGMENTS

We extend our gratitude to all individuals who contributed to the planning, development, and publishing of this 60th CTTE Yearbook. It is an honor to continue the spirit of collaborating with professionals dedicated to research and expression of facts, perspectives, and potential directions for technology and engineering teacher educators.

We are especially indebted to the authors for their scholarly contributions, responsiveness, and professionalism. Special recognition is directed to the willingness and insights provided by this diverse team of authors who examined creativity and design from the vantage points of their various professions both within and external to technology education. We also express sorrow for the passing of Dr. Gerald Day before this yearbook was published. We would like to honor his Chapter 4 authoring contributions on the development of humans as well as his dedication to the preparation of technology and engineering teachers throughout his professional career.

The Yearbook Committee is thanked for their assistance in the yearbook proposal and production process. Special efforts were expended in preparing both the electronic edition of the CTTE Yearbook as well as continuing the traditional printed publication.

A note of appreciation is extended to Mrs. Linda Deal for her assistance in preparing the Index. We acknowledge the encouragement and support provided by our colleagues at Millersville University. We also recognize the valuable personal support that we have received from our spouses (Toni Warner and Kay Gemmill) and our families.

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INTRODUCTION

The world is shrinking! The connectivity of communications is bringing us all together. No longer can we think of ourselves as members of a tribe, village, city or nation, but rather we are facing the dilemmas and opportunities of becoming citizens of the entire planet. In this expanded context, we look at ourselves and wonder about the role that we should play, how best to make a contribution and how to keep pace with constantly accelerating change. We realize that the implementation of another version of an accepted practice is no longer enough, but rather that we must learn to find something new, to change the framework and think in new and unexpected ways. Creativity and design must be added back into education to make this happen.

We must continue to teach young people in the best traditions of invention, engineering and science, to become expert innovators and rigorous thinkers, but at the same time we need to help them develop the subtleties of the arts, able to harness the power of intuition and lateral thinking, moving fluently from one side of the brain to the other. This is where creativity and design go hand in hand, as design and design thinking provide a bridge between logical and intuitive thinking, between objective and subjective, between the reasonable realm of explicit knowledge and the fuzzy soup of tacit understanding. Successful concepts mix creative “Aha” moments of inspiration with careful analysis and structured development processes. This yearbook explains how to combine creativity and technology, teaching a future generation how to discover what needs to happen next as well as how to enable it.

Four themes inspire the scholarly contributions in the chapters that follow. The first helps us understand how creativity and design are inextricably intertwined, as design processes have evolved over centuries to enhance creativity through lateral thinking, conceptual blockbusting, intuitive problem solving, and subjective synthesis. The second theme looks at how the brain can achieve the partnership between logic and intuition, explaining how we develop into adults, the cognitive activities in the hemispheres of the brain, and the connections between innovation, creativity, and design thinking. The third theme looks at the physical and cultural conditions that are needed to educate successfully, showing that physical environments are important and that a culture that embraces qualitative attributes is essential. The fourth theme is a call for action, looking at the ways and means of promoting creativity and design in technology education, as well as professional development for technology teachers.

This yearbook provides a guide and inspiration to help a new generation find a creative and sustainable place in a high technology and socially connected planet.

Bill Moggridge,
Director of the Smithsonian's Cooper-Hewitt National Design Museum

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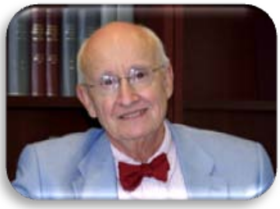

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Providing the Context for Creativity and Design in Technology and Engineering Education

Chapter 1

Scott Warner
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I recently went to breakfast with my wife, children, and some family members who were visiting from another state. We went to a family oriented restaurant, one of those franchise establishments that provides a menu with a list of entrees that is consistent from site to site, state to state, and region to region. The establishment used the theme of "Americana" for its ambiance. Throughout the restaurant were displayed antiques of all sorts. Pictures of people, old signs, tools of various types and vintages, toys and other amusements including ice skates and snow sleds, and ephemera such as old boxes of laundry detergent, were all mounted to the wall or placed on shelves as forms of decoration. For my children, when they were not trying to annoy each other, these artifacts from the past served as a sort of informal museum of American history. However, I saw something very different. Unlike a museum where there is usually a plaque printed with information to provide the viewer with some piece of the history for each artifact, these displays were bare, devoid of context and story. I guess the historian in me felt let down by the lack of this type of information. The photograph from the early part of the 20th century that looked like it might be of a group of soldiers who had just completed basic training had no history to share with its audience. The tools were, for the uninformed, just decorations and not symbols of the creativity and ingenuity of the craftspeople and laborers who solved everyday problems with the resources they had at hand. The old signs were unable to tell the full story of the entrepreneurial spirit that manifested itself in a company that may no longer exist, making a product that is no longer needed, but which in its time was an employer of people anxious to make a better life for themselves and their children.

These artifacts being displayed without any context, without any story, saddened me because I felt like I was being served a type of meal that was missing an important ingredient. Instead of this meal satisfying my curiosity and my mind, it left me feeling empty and disappointed, an opportunity missed. In my opinion, a similar meal is being served to the technology education profession when it comes to creativity and design. I am also saddened by my perception that, in the United States at least, the full richness and flavor of creativity and design cannot be savored and enjoyed by both the teachers of technology and their students. Multiple factors have contributed to why this has come to pass. Historical, economic, political, and cultural forces have contributed in both overt and subtle ways as to why creativity and design has had, for the most part, a back seat to technical and vocational goals and objectives toward the study of technology. Other countries around the world have had different interpretations of the role of creativity and design toward the study of technology. Though none of them has achieved some “ideal” manifestation of creativity and design in their study of technology, each brings additional types of metaphorical food to the table so that all can enjoy a more complete meal. Other fields of human endeavor have also added their own ingredients to our increasing understanding of creativity and design. Fields such as medicine, psychology, education, and fine and performing art, as well as professions such as architecture, engineering, industrial design, and graphic design have all had an ongoing interest in defining, understanding, and developing creativity through design. For those in education in general and those in technology education in particular, there is a need to begin bringing these disparate perspectives together. That is why, in part, this yearbook came into existence.

This chapter will provide a context in which creativity and design can be recognized as a central focus for the study of technology. Toward this goal the chapter will briefly examine the contextual settings of (a) the properties of creativity and design, (b) the origins of creativity and design, (c) the role of creativity and design within the world of technology, (d) historical precedents for creativity and design in technology education curricula, (e) the importance of creativity and design within *Standards for Technological Literacy* (*SfTL*) by the International Technology Education Association (ITEA, 2000), (f) the role of creativity and design in curriculums around the world, and (g) the future of creativity and design within the evolving curricula of technology education. This chapter will also set the stage for the other chapters of this yearbook, which will explore in depth the various aspects of creativity and design in technology education.

PROPERTIES OF CREATIVITY AND DESIGN

Creativity and design have many definitions, as the reader will discover throughout this book and especially in the next chapter. However, it will be helpful to establish what these terms mean in general so as to facilitate what is written about here in the first chapter. Let us first consider creativity. Many experts have spent years exploring the nature of creativity. Hope (2004) emphasized that most of the expert research on creativity has placed it in a setting that is "context dependent and socially determined and assessed" (pp. 36-37). She later went on to write that creativity, as expressed through design, within the context of the curriculum of Design and Technology should not be based just on divergent thinking (coming up with lots of ideas). Hope's perspective was

> The phrases 'possibility thinking' and 'as if' thinking (Craft, Dugal, Dyer, Jeffrey, & Lyons, 1997) are useful ways of defining creativity in a Design and Technology context. Thinking of possibilities not only implies the ability to think of lots of ideas but also relates those ideas to the specifics of the problem in hand: *What is possible in this given situation?* (p. 38)

My own efforts to research and understand creativity within the context of a technology education classroom have led me to come up with a definition of creativity that seems to meet all, or at least most, of the criteria established in the literature (more on those criteria in Chapter 2). I defined creativity as "a human act or process that occurs when the key elements of novelty, appropriateness, and a receptive audience in a given field come together at a given time to solve a given problem" (Warner, 2000, p. 11). These similar definitions address both the importance of context and the need for those properties that separate the ordinary thought, action, or behavior from those that would be considered creative.

Hutchinson and Karsnitz (1994) defined design as simply "the planned process of change" (p. 18). Even with such a simple definition design is often only thought of within the context of the design-based professions such as architecture, industrial design, graphic design, engineering design, painting, sculpting, and the many other fields of technological and artistic design. This perspective, though it does provide plenty of opportunity for insight into how professional designers think and act, tends to limit the perceptions toward design thinking and design actions as being something that is the sole possession of professionals (i.e., only trained experts can be designers). Such a perception is completely false. Every human with even a minimal amount of cognitive capability uses design thinking and takes design actions every day, which then makes this person a designer. How is this so? According to Pye (1978) design is ubiquitous to the human made world:

> The art of design, which chooses that the things we use shall look as they do, has a very much wider and more sustained impact than any other art. Everyone is exposed to it all day long. Indeed, in towns there is hardly anything in sight except what has been designed. The man-made world, our environment, is potentially a work of art, all of it, every bit of it. (p. 11)

A report from the Royal College of Art (as cited in Cross, 2007, p. 17) went even further in defining the scope and nature of design as "the collected experiences of the material culture, and the collected body of experience, skill and understanding embodied in the arts of planning, inventing, making and doing." Cross's analysis of the report resulted in the development of the following list of four characteristics of design:

- The central concern of Design is 'the conception and realization of new things'.
- It encompasses the appreciation of 'material culture' and the application of 'the arts of planning, inventing, and making and doing'.
- At its core is the 'language' of modeling; it is possible to develop student's aptitudes in the 'language', equivalent to aptitudes in the 'language' of the sciences (numeracy) and the 'language' of humanities (literacy).
- Design has its own distinct 'things to know, ways of knowing them, and ways of finding out about them'. (Cross, 2007, p. 17)

This analysis by Cross lead him to come up with a new word to better describe the nature of the design approach to thinking and doing. That word was "designerly" (p. 17). As the reader will see in this chapter and in the rest of this yearbook, the designerly ways of knowing and doing are deeply rooted in the human psyche, both in how we have evolved biologically as a species and in how we have evolved through the human-made construct of culture.

ORIGINS OF CREATIVITY AND DESIGN IN BIOLOGY AND EVOLUTION

Being creative through design is a fundamental part of what it means to be human. We humans have been changing and shaping the natural environment to suit our needs for at least 2.5 million years. Though early human ancestors were probably making such changes much earlier, the physical evidence of the use of technology would not become enduring until they started making and using stone tools. Johanson, Johanson, and Edgar (1994) argued that the advent of technology through stone tools represented a profound shift in the way humans think. Making such a long lasting tool represented the maker's ability to not only deal with the here and now but also indicated connections to the past through experiences as well as connections to an anticipated future. It is important to note that the creative act of making stone tools did not materialize out of thin air. The making of the first stone tools must have had plenty of precedent with the creation of earlier tools made from less enduring materials such as wood and other plant matter, and animal bones and horns. However, for any of these creative acts of tool making to have occurred there first needed to be biological changes to the architecture of the bodies of our ancestors.

The very first evolutionary development that would facilitate the creative potential of the human species occurred while our ancestors were still living an arboreal life. That development was three-dimensional color vision. Hoffecker (2011) described the environmental pressures that led to evolutionary changes in the vision systems of early human ancestors. Those pressures were based primarily on their need to be able to survive in the trees. Color vision most likely evolved as a response to the need to identify ripe fruit in a canopy of green leaves, and three-dimensional vision enabled our tree dwelling ancestors to successfully prey on "small, fast-moving vertebrates and insects" (p. 40).

The eventual movement of our earliest ancestors down out of the trees and onto the savannas resulted in many changes to how they used their bodies. No longer were our ancestors using their hands and feet to move about from branch to branch and across the ground in a quadrupedal fashion. The evidence indicates that the next biological changes toward becoming modern humans occurred with the evolution of locking knees, an upright skeleton, and bipedalism (Schick & Toth, 1993; Johanson, Johanson, & Edgar, 1994; Burke & Ornstein, 1995).

Unlike our chimpanzee and gorilla cousins, who must use muscle power alone to maintain a bipedal stance for short bursts of time, human ancestors were able to lock their knees and stand upright at all times. This evolutionary innovation enabled our ancestors to have their arms and hands freed up to do other things, such as making tools (Johanson, Johanson, & Edgar, 1994). The hand and the arm would also go through a series of evolutionary changes that would result in modern humans having high levels of control and manipulation through the fingers, the thumb, the wrist, and the arm. Wilson (1998) described the functional advantages of these changes to "Lucy," a 3.2 million year old fossilized human ancestor who was discovered in the Hadar region of East Africa in 1974, when he stated

- The thumb, index, and middle fingers can form a 'three-jaw chuck,' which means the hand can conform to, grasp, and firmly retain irregular solid shapes (such as stones);
- Finer control can be exerted over objects held between the thumb and the tip of the index and middle fingers;
- Rocks can be held within the hand to pound repeatedly on other hard objects (nuts, for example), or to dig for roots, because the new wrist structure is able to absorb (dissipate) the shock of repeated hard strikes more effectively than the ape hand. (p. 26)

Those increased physical capabilities and manipulative refinements in the hand, fingers, wrist, and arm have been passed down through the eons to modern humans.

With each of these variables in place it became possible for human ancestors to begin using creativity to shape their environment by making and using tools. It was with the continuous use of tools (DeVore, 1980) and a change of diet to include meat to provide additional fuel for the functions of the brain (Johanson, Johanson, & Edgar, 1994) that the human brain began to grow in size and change in its capacity for abstract thought. Burke and Ornstein (1995) described this interaction among the hand, diet, and environment toward the evolution of the brain as being a type of self-generating system where ”busy brains are big brains, and so by two and a half million years ago hominid brain size had doubled" (p. 10). Schick and Toth (1993) observed that the brain casing of human ancestors would continue to increase in size over the course of the 3.2 million years that separate modern humans from our ancestor Lucy. Lucy's kind is called *australopithecus afarensis. A. afarensis* had a brain case of between 350 and 500 cubic centimeters (cc), approximately the same size as a modern chimpanzee or gorilla (p. 44). Next came the first of the homo genus, *homo habilis*, who had a brain casing size of 600-750 cc (p. 81), slightly larger then *a. afarensis* and approximately half the size of modern humans. Next on the human family tree came *homo erectus* who had a brain casing size of 850 to 1,100 cc (p. 229), considerably larger then *a. afarensis* and about two-thirds to three-quarter the size of modern humans. Modern humans, *homo sapiens*, first appeared about 120,000 years ago (Burke & Ornstein, 1995). According to Schick and Toth (1993) the brain casings for modern humans average in size at 1,350 cc (p. 44).

From the perspective of the technology education teacher the relationship between the hand and the brain of modern humans is central to the very existence of technology education as a curricular area. Historically, that relationship has been the underlying rationale for the efforts of educators from Johann Pestalozzi, to Calvin Woodward, to William E. Warner, to Donald Maley, to all of the many other hands-on programs that have been proposed and implemented over the generations, to those who are currently leading the technology education profession into a greater alignment with engineering. Brown, in a video recorded at the 2008 Art Center Design Conference, summarized the importance of this relationship between hand and brain best when he stated, "The human hand in manipulation of objects is the hand in search of a brain [and] the brain in search of a hand . . . ." Furthermore, as neurologist Wilson (1998) described this relationship, it is clear that the use of the hand, as well as the wrist and arm, has established organizing structures in the brain that fundamentally influence the way humans think. Wilson argued that our sense of spatial positioning, our physical coordination, our abilities to take in sensory stimuli, our abilities to interact with the surrounding environment, and a whole host of other aspects of what it means to be human are closely linked to the evolutionary development of the relationship between hand and brain. Looking at the depth and breadth of this relationship from a strictly biological and evolutionary perspective it should make all educators wonder as to why hands-on learning is not a part of every classroom at every school level. For technology educators it should be an affirmation of the valuable contribution classes in technology education make toward shaping young people into more fully formed human beings.

The evolutionary developments in the physical structure of humans have provided the biological scaffolding for the expression of creativity through design. It is only in the world of the imagination that we could speculate as to how much different creativity and design would be, or even could be, expressed by humans who had evolved with different physical attributes at their disposal. Regardless of the speculations of that fantasy world, humans have used these biological tools—three-dimensional color vision, locking knees, upright skeleton, grasping hands with opposable thumbs, and increasingly larger brains—to use our creative capabilities through design to successfully control our natural surroundings and thrive as a species for the last 3-4 million years.

CREATIVITY AND DESIGN WITHIN THE WORLD OF TECHNOLOGY

Bronowski (1973) in his book *The Ascent of Man* eloquently made the connections between the spirit of humankind and the artifacts that we have made through our art, our sciences, and our technology. In each of these areas humans have used creativity and designerly actions to make discoveries, inventions and innovations, and new music and art. On this theme Bronowski stated

> I have described the hand when it uses a tool as an instrument of discovery . . . . We see this every time a child learns to couple hand and tool together—to lace its shoes, to thread a needle, to fly a kite or play a penny whistle. With the practical action there goes another, namely finding pleasure in the action for its own sake—in the skill that one perfects, and perfects by being pleased with it. This at bottom is responsible for every work of art, and science too; our poetic delight in what human beings do because they can do it. The most exciting thing about that is that the poetic use in the end has the truly profound results. Even in prehistory man already made tools that have an edge finer than they need have. The finer edge in its turn gave the tool a finer use, a practical refinement and extension to processes for which the tool had not been designed.
>
> . . . The hand is the cutting edge of the mind. Civilization is not a collection of finished artefacts, it is the elaboration of processes. In the end, the march of man is the refinement of the hand in action. (p. 116)

Unfortunately, space limitations allow for nothing more than a cursory discussion of the full relationship of creativity and design within the world of technology. Williams (1987) observed that technologies enabled humans to develop cultures, which were built upon foundations of such basic technologies as "agriculture, building, pottery, and textiles" (p. 10). Expressions of creativity and design would be represented in both the creation of the artifact and in the aesthetics of its final form. As an example, the potter's wheel would represent its own linage of invention and innovation from the invention of the wheel by the Mesopotamians sometime around 4,000 BCE, to the eventual development of a small turntable called a "tournette" about a thousand years later (Bryant, n.d.), to the first potter's wheel with a foot or kick wheel developed sometime around 2,400 BCE in Egypt (Hellmold, 2001). These developments in the machine used for creating pots are examples of creativity and design affecting a technology. These improvements in the potter's wheel lead to refinements in the actual pot and its physical form, another avenue for creativity and design in this area of technology. The refined potter's wheel also provided avenues for other expressions of creativity and designerly actions in the realm of the aesthetic. As Williams noted, "From a very early date the potter's vessels were often richly ornamented, demanding a practical skill in glazing" (p. 10). The act of decorating the pots with glaze is a good example of the interaction of art and technology (and eventually the sciences) through the medium of creativity and design. This symbiotic relationship between technology and art and later among technology, art, science, and engineering has roots going back to our ancestors making stone tools on the savannas of Africa.

The role of creativity and design in the story of technology is a fascinating tale. Writers such as Burke (1978, 1985, 1996), Bronowski (1973), Cardwell (1995), Kranzberg and Pursell (1967), Williams (1987), and many others have written about the individuals and groups, both known and unknown, and the inventions and innovations that they created. Those stories are all laced with examples of creativity and intentional acts of design that parallel the story of the development of pottery and the potter's wheel. For the teacher of technology education this extensive history should represent a rich repository of examples of what others have done to use creativity and design to solve a given problem in a given time and place.

PRECEDENTS FOR CREATIVITY AND DESIGN IN TECHNOLOGY EDUCATION CURRICULA

Standards for Technological Literacy (ITEA, 2000) acknowledged the ever-present link between creativity and design by stating "Technological design inevitably involves a certain amount—sometimes a great deal—of human creativity" (ITEA, 2000, p. 91). However, the presence of creativity and design within the curricula of technology education and its predecessors has not always been overt. Woodward (1887), who was an advocate of an early form of technological education known as manual training, made a forceful argument for an approach to liberal education that included the use of hands-on experiences. He stated

> No education can be 'free' which leaves the child no choice . . . . A truly liberal education educates equally for all spheres of usefulness; it furnishes the broad foundation on which to build the superstructure of a happy, useful, and successful life. (pp. 202-203)

Woodward further observed, "The education of the hand is the means of more completely and efficaciously educating the brain" (p. 205). Though Woodward lived in a time in history that was deeply entrenched in a growing American Industrial Revolution, and vocational and industrial objectives strongly influenced the educational thinking and writing of the era, he still wrote about manual training in holistic terms that reflected the importance of developing not only the hand and related skills but also the intellect, the moral character, and the physical body of the student. This broad range of goals at the Manual Training School was best summarized when he stated

> The object of the introduction of manual training is not to make mechanics. I have said that many times, and I find continual need of repeating the statement. We teach banking, not because we expect our pupils to become bankers; and we teach drawing, not because we expect to train architects or artists or engineers; and we teach the use of tools, the properties of materials, and the methods of the arts, not because we expect our boys to become artisans. We teach them the United States Constitution and some of the Acts of Congress, not because we expect them all to become congressmen. But we do expect that our boys will at least have something to do with bankers, and architects, and artists, and engineers, and artisans; and we expect all to become good citizens. Our great object is educational; other objects are secondary. (p. 229)

Creativity and design were subtle and indirect in the writings and philosophy of Woodward. As noted by Lewis and Zuga (2005), Woodward's primary objective was, after all, the development of "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" (p. 15). In the closing decade of the 19th century and the opening decades of the 20th century, changes in the broader culture and within the community of technological educators would result in the presence of creativity and design becoming overt within the curricula of manual training, manual arts, and later industrial arts. A significant change in the culture that influenced the role of creativity and design in the technological classroom was the Arts and Crafts Movement.

The Arts and Crafts Movement originally started in England at the end of the Victorian period and would quickly find acceptance in the United States (Obniski, 2008). This movement was a reaction to the increasing mechanization of the Industrial Revolution and to the ostentatiousness of Victorian life-styles. Though often only thought of today as a style of home furnishing, the movement had at its core social and philosophical goals aimed at the betterment of humankind. Ellis, writing in the Foreword for the book *In the Arts and Crafts Style* (Mayer & Gray, 1993) described the movement's goals as being "concerned as much with questions of social reform as with issues of design aesthetic" (p. 9). Bennett (1937) explained how the philosophies of the movement found their way into the manual arts/industrial arts classroom by citing a statement of principle from the Society of Arts and Crafts in Boston issued in 1904, which stated

> The conditions of true handicraft are natural aptitude, through technical training, and a just appreciation of standards. The unit of labor should be an intelligent man, whose ability is used as a whole and not subdivided for commercial purposes. He should exercise the faculty of design in connection with manual work, and manual work should be part of his training in design. (p. 441)

Bennett then noted that "The ideal set forth in the last sentence of this paragraph was at once accepted by many educators as a goal for the manual training and the art work in the schools" (p. 441). Unfortunately, just accepting such an ideal does not automatically prepare a teacher for what it means to teach with creativity and design in mind. As Bennett later explained

> some of them [Arts and Crafts activities] were unsuccessful because the teachers in charge of the shop instruction were not adequately trained in design and in teaching by the creative method. Training in both was needed to produce satisfactory educational results. (p. 442)

Obniski (2008) noted that by the 1920s the philosophical influences of the Arts and Crafts Movement would fade from both the general culture and the classroom as a result of "the rise of urban centers and the inevitability of technology" (para. 10). However, this movement would leave a lasting legacy in the education programs of the United States and Great Britain in that creativity and design were now explicitly identified in the literature and the curricular goals of manual and industrial education (Bennett, 1937; Herschbach, 2009; Lewis & Zuga, 2005).

The early decades of the 20th century provided fertile ground for the growth and development of progressive thinking toward education that was supportive of the type of hands-on educational experiences that Cross (2007) would later identify as designerly. At the cutting edge of the progressive movement in hands-on education were individuals such as Dewey, Bonser, and Mossman. All three of these individuals served as teacher education faculty at Columbia University. Lewis and Zuga (2005) described their work as being concerned

> 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 [to] improve upon their conditions and society (p. 19).

The role of industrial arts toward social reconstruction was to put students in the position of critically examining how technology, and the human made decisions about the development and use of technology, affected their world. This approach to teaching and learning about the arts of industry was future directed in 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. (Lewis & Zuga, 2005, p. 20)

Bonser and Mossman (1931) were also at the front end of teaching about designerly thinking in that they espoused the use of school-based activities to develop in students the types of thinking and learning practices that would facilitate critical thinking and analysis as well as creativity. Their position on this matter was as follows:

> 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 the 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. Questions of What, and How, and Why have to be answered if the work is anything more than dictation responses. Information must be acquired in relationship to the definite problems. The imagination must be used in seeing the procedure as a plan of action to be carried out. (pp. 46-47)

They later went on to write that design is a fundamental tool for understanding the human-made world. Furthermore, having young people actively engage in making and doing through design was an important developmental tool for educators teaching about the human-made world. In their opinion

> Children should design, or have a large part in designing, every object which they make. This is one means of developing judgment and taste. In working out the designs for the products made in each respective industrial field, the detailed principles of design as they are called for may be taken up with increasing degrees of complexity as ability develops. Beginnings will have to be simple, but through them knowledge and judgment will grow. Provision for choice will have to be extensive, and the opportunities for making mistakes will furnish the necessary basis for constructive criticism and help. (pp. 59-60)

A generation later Wilber (1948) wrote about the importance of critical thinking, which he felt could "be developed only through practice in solving problems" (p. 9). He also provided the reader with a list of the common objectives that an industrial arts teacher should address when selecting the subject matter. Wilber's list of common objectives included (a) "To increase an appreciation for good craftsmanship and design, both in the products of modern industry and in artifacts from the material cultures of the past" (p. 70), and (b) "To encourage creative expression in terms of industrial materials" (p. 77). All of Wilber's objectives provided the industrial arts teacher with lists that specifically addressed the expected "behavior changes from students" and suggested "lessons, projects, activities, etc." that originate from, or contribute toward the objective. These two objectives previously identified, in particular, were built upon a strong foundation of creativity and design that encouraged students to make their own decisions, to be critical and analytical thinkers in harmony with their use of creative thinking, to appreciate good design in their own work and in others, and to actively engage with tools, machines and materials to express their creativity through design.

A contemporary of Wilber (1948) was Osburn (1948), who authored a book entitled *Constructive Design*. In the introduction of his book Osburn directly addressed his intended audience by stating

> This book is written especially for the teacher of industrial arts. It is based on the assumption that making things is not enough in itself, valuable as it may be. To bring the greatest returns the making should be preceded by planning. The power of thinking—planning—designing—is a necessary part of the learning process which may, like other skills, be taught and improved. (p. vii)

Osburn then provided the reader with a series of descriptions of the components of what makes someone a good designer, what makes something a good design, and how good design can be applied to the various materials of the human-made world. One of the early sections was entitled "What Can The Designer Believe?" and it provided the reader with the following eight statements of belief:

1. Designing is reflective thinking working in visual form.
2. The designing technique (the process of being creative) is identical with the scientific method, and must be developed by study and practice to be effective.
3. Being creative is not an act of spontaneous generation by a mind untrained and uninformed.
4. Emotion, which may or may not accompany creative activity, is the result of the feeling of satisfaction (or lack thereof) in the rightness of the effort.
5. Dexterity, power of visualization, and general intelligence, are the forces that make for competency in designing in the visual arts, as well as constituting skill in producing them.
6. Painting, drawing, weaving, forging—in fact, all visual arts—are produced by the same common elements. Differences in the success of those who practice them are measures of quality of effort and quality of thinking, rather than differences of kind.

7. Rightness—beauty—is and always has been relative to the times and circumstances. To hold that there are permanent standards of beauty such as the “golden rectangle,” irrespective of when or how used, is, in the language of Croce[1], to cling to the “astrology of aesthetics.”
8. A democratic viewpoint can hold no hierarchy of rank among those who create, except that of the relative social worth of their contributions. (p. 2)

Wilber and Osburn are only two of the many writers in the field of industrial arts at the middle of the 20th century. Their perspective on creativity and design in the industrial arts curriculum was overt and direct. I would also argue that their perspective on the role and value of creativity and design toward learning about the arts of industry is amazingly progressive and one from which any contemporary technology education or technology and engineering educator could learn.

One of the most progressive programs in industrial arts teacher training from the 1950s was the Minnesota Plan. Developed by Micheels and Sommers (1958), the program was intended to be a transitional tool as industrial arts teacher education moved toward the study of technology. The program was organized around what was referred to as the three “cores of experience,” which consisted of science-mathematics, technology, and design (Cochran, 1970; Herschbach, 2009). Herschbach identified the fundamental nature of design in this program by writing

> The design core served as the means through which the learning experiences in the scientific and mathematics core and the technology core were applied to problem-solving experiences with tools, machines, and processes. In other words, the design core would represent the culmination of the other learning experiences as students engaged in actual design tasks. (p. 80)

By the 1960s another generation of industrial arts educators would put their own stamp on the role of creativity and design. Early in that decade, as one example, Lindbeck (1963) wrote a book entitled *Design Textbook*. His explorations of design concepts were categorized into the three broad topics of designing and teaching, background for design, and constructive design. His book provided the profession with at least one tool for addressing the teacher preparation shortcomings identified by Bennett (1937) with the attempts to bring the Arts and Crafts movement into the manual arts/industrial arts classroom. Later in the decade, as another example, Scobey (1968) would take an integrative approach to all of the subject areas, including industrial arts, and put them into an elementary school context with *Teaching Children about Technology*. The author summarized the importance of creativity and design as it applies toward teaching children about technology when she wrote

> Industrial products utilize artistic detail and design, for man has always had the tendency to beautify the materials he transforms for use. He has been creative in the way he formulates, decorates, and arranges the things about him. Primitive bows, modern boats, and airplanes are created with beautiful as well as functional lines. . . . Because this fundamental desire for beauty is in all that is produced, fine art and industrial arts are closely and vitally related. (p. 21)

The second half of the 20th century was a period of upheaval for industrial and technological education. In the first half of the century, industrial arts was a comfortable fit into the general curriculum of public education because of the importance of industry to the overall American culture. However, things began to change in the 1960s. According to Herschbach (2009) industrial arts would split into “three discernable program lines” (p. 71). The first line he labeled “the utilitarian value of industrial arts” (p. 72), which took the position that the primary instructional goal of industrial arts was the promotion of technical skill development. From the utilitarian perspective creativity and design were at best secondary educational goals, if they were even present at all. According to Herschbach, this approach had broad support with many industrial arts educators and in the general community, especially after the Second World War. In the 1970s things began to change as concern for the perceived slip in the academic capabilities of American students resulted in a questioning of the value of industrial arts toward the general education curriculum. Herschbach noted that the political milieu of the 1980s and the publications of such documents as *A Nation at Risk* (Gardner, et al., 1983) resulted in elective programs, such as industrial arts with a utilitarian perspective, moving to the background for many students as the public schools began refocusing on the core academic subjects.

The second program line identified by Herschbach (2009) was the “progressive influence” (p. 73). The progressive approach to industrial arts was built upon the philosophical foundation of work by Bonser and Mossman at Columbia University. A progressive approach to teaching industrial arts typically meant that the instructor was willing to address both the social and political implications of the development, use, and existence of a technology. These types of explorations, especially during periods of conservative retrenchment within the broader culture, would often result in both programs and program supporters being politically attacked. According to Herschbach, by the end of the 1970s only fragments of the educational progressivism of the early 20th century would still manifest themselves in the industrial arts curriculum. There were exceptions to this slow slide away from progressive ideals. Perhaps the most notable was Donald Maley and his work with *The Maryland Plan* (1973). Herschbach described the importance of Maley's work this way:

> Maley's work is significant in that it offered a curriculum alternative to those industrial arts educators who were searching for a more student-centered approach to instruction in the 1970s and early 1980s. Almost alone, he challenged more technocratic concepts of industrial arts. (p. 74)

Some aspects of progressive industrial arts curriculum and instruction that can still be found within the profession in the initial decades of the 21st century include studies of inventions, issues related to the environmental impact of technologies, open classrooms, learning centers within the classroom/laboratory, using cooperative learning techniques, the understanding and use of concepts related to developmental psychology, and student-centered instruction. These remaining vestiges of the progressive approach to industrial arts are important building blocks for a strong technology education or technology and engineering program. These building blocks help to provide the curricular and cultural scaffolding necessary for the healthy growth and development of student creativity through a designerly approach to teaching and learning.

The third program line for industrial arts identified by Herschbach (2009) was that of "technology and industrial arts" (p. 75). The idea of using technology as the focal point for industrial arts curriculum has had a history that goes back at least to the 1940s and William E. Warner's work with a group of his graduate students to propose *The Industrial Arts Curriculum: Development of a Program to Reflect American Technology* (1953). Herschbach noted that the 1960s was a decade of active development for industrial arts curriculums. One measure of the amount of developmental activity was Cochran's (1970) identification of 20 significant curriculum projects from this one decade alone. In Herschbach's opinion this proliferation of curriculum development projects was because "industrial arts had to reconstitute itself if it was going to survive as a viable subject" (p. 76). Toward this end the 1960s could be considered the gestation period for the transition from industrial arts to technology education. During the 25- year period from 1960 to 1985 the concepts of technology education were discussed and debated by the members of the profession. As a result of this long conversation the stage was set for the changes that would come about in the 1980s. Those changes included the *Jackson's Mill Industrial Arts Curriculum Theory* (Snyder & Hales, 1981), which provided a rationale for the shift to technology education, and the name change in 1985 of the *American Industrial Arts Association* (AIAA) to the *International Technology Education Association* (ITEA), which provided an organizational label that aligned the profession with the study of technology.

These three approaches to industrial arts contributed their own respective legacies toward the use of creativity and design in contemporary technology education and technology and engineering education programs. The utilitarian perspective provided a legacy that contributed toward the continuing perspective of technology education as primarily an educational opportunity for technical skills development. Previous research I have done on the nature of design in technology teacher preparation has shown that there is a continued emphasis on the techniques of design (Warner & Morford, 2004). This study divided design focused courses into two categories. They were technique-based courses, which were "focused on the technical aspects of design" (p. 36), and synergistic-based courses, which "combine the technical skills with the overall thinking processes of design" (p. 36). The research revealed that there was a six to one difference between the number of technique-based design courses and the synergistic-based courses offered to the typical undergraduate technology teacher educator. As noted in a follow-up study that investigated the paradigm of design faculty in undergraduate technology teacher education programs, "It is important to remember that the influences exerted on pre-service technology educators on how they interpret technological design will continue to have consequences for the profession at all levels of education for decades to come" (Warner, Morford Erli, Johnson, & Greiner, 2007). As a result, the utilitarian perspective with its diminished emphasis on creativity and design will be a presence in technology education and technology and engineering education for some time.

The progressive perspective, as discussed earlier, never entirely went away. Herschbach (2009) even went so far as to write

> The early concept of industrial arts as expressed by [such leaders in the profession as] Richards, Russell, Bonser, and Mossman is compatible with technology education in many ways. . . . In some respects, the shift to technology education represents a shift in terms, not meaning. (p. 127)

This confluence among the goals and objectives of the progressive influence in industrial arts and the efforts to transition toward technology education provided avenues for these combined program lines to succeed in ways that neither had accomplished alone. Their combined legacy, and the importance of creativity and design within the study of technology, would first manifest itself through a document entitled *Technology for All Americans* (ITEA, 1996), which created "a rationale and structure for the study of technology" (p. 44) with the explicit goal of establishing that "Technological literacy must become a central concern of the educational system" (p. 44). This document ultimately lead to *Standards for Technological Literacy* (ITEA, 2000; *SfTL*), which integrated many of the humanistic goals and objectives of the progressive line of industrial arts with the study of technology using design as the primary tool of investigation.

CREATIVITY AND DESIGN WITHIN STANDARDS FOR TECHNOLOGICAL LITERACY

SfTL (2000) established the conceptual framework for the content of the study of technology. As an informal goal, *SfTL* also served as a tool to help the technology education profession make the move toward the study of technology in a coherent fashion. Essentially, *SfTL* provided a common frame of reference that could be used by teachers, teacher educators, administrators, and others interested in developing technological literacy in young people. Lewis (2005) however, argued that studying content, though an important first step, was not enough. Lewis advocated for the use of creativity "as an important goal of technology education, and as a concomitant of the goals of the Standards for Technological Literacy" (pp. 35-36). Lewis and Zuga (2005) best summarized why *SfTL* was so focused on content by writing

> 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 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. (p. 66)

In spite of the various political and cultural pressures of the time, *SfTL* provided some important forays into the realm of creativity and design. A review of the document and an informal count of the number of times that the word "design" or other variations of that word appear within the body of the text revealed almost 700 examples over 219 pages. The emphasis on design and problem solving within the *SfTL* was explicit. Unfortunately, the importance of creativity in general within *SfTL* was at best implicit. An informal count of the number of times that the word "creativity" or other variations of that word appear within the body of the text of *SfTL* revealed only 42 examples over 219 pages. Lewis' (2005) reaction to the diminished emphasis on creativity in *SfTL* was that

> There is a need for design and problem solving in technology education to be framed not so much in terms of methodologies of engineers, but as opportunities for students to step outside of conventional reasoning processes imposed by the rest of the curriculum. Creativity has compelling claims to being the anchoring idea in such a framework. (p. 36)

The emphasis on design within *SfTL* represented a significant leap forward toward creativity and design becoming the principle tools, within the context of a technology education program, for young people to learn how to examine, develop, use, adapt, and dispose of technology. Writing in the Preface of *SfTL,* Dugger and Gilberti, noted that the document "does not represent an end, but a beginning" (ITEA, 2000, p. viii). Lewis (2005) observed that the technology profession had reached a stage of development

> . . . where the subject in the curriculum from which technology education increasingly takes its cue is science, with its exactness;

> but it may be that we can benefit from alliances with 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. (p. 46)

Perhaps the next stage of development for the technology education profession should be the advancement of the creative expressions that the study of technology can facilitate. The goal of technological literacy is and will continue to be a worthy pursuit. However, is that goal enough to sustain technology education in the general education curriculum? Are there examples around the globe of other curriculums where the goal of technological literacy and expressions of creativity through design have equal status?

THE ROLE OF CREATIVITY AND DESIGN IN CURRICULUMS AROUND THE WORLD

Around the globe there have been many curricular efforts to bring the study of technology through creativity and design into the educational diet of school children. Jones (2009) specifically identified curriculum development efforts in "Australia, the United Kingdom, USA, Canada, Europe, South Africa, and New Zealand that emphasise the importance of students developing technological literacy" (p. 13). What sets these various technology education curriculums apart from prior efforts that were primarily focused on craft? De Vries (2009) argued that in an increasingly complex and globalized world it is necessary for the various technology curriculums found in different countries to use design as the primary tool for "helping student to develop an appropriate concept of technology, an understanding of the basic concepts in technology, and a positive-critical attitude towards technology" (p. 5). De Vries went on to elaborate on this position by writing

> It is best to give students experiences in undertaking the process of technology. Going through a process of designing is probably the best way to learn that technology is a human endeavour in which decision making, based on normative judgments, and the use of a variety of knowledge domains plays a vital role. This approach has the additional advantage that it connects the various types of literacies that are aimed at in general education; designing entails the use of language, symbols, and numbers. In this way, doing

design connects technological literacy with linguistic and numerical literacy. (p. 5)

Perhaps one of the oldest and most elaborated curriculums to accomplish what de Vries was advocating is Design and Technology (D&T) in the United Kingdom (England and Wales; UK). The history of D&T goes back at least, in some form, to the 1930s. Atkinson (1990) described that history as having "progressed from single material, craft-skill based courses for the less able to a thinking, feeling, doing activity drawing on and linking with a wide range of subject bases for all pupils of compulsory school age" (p. 1). From 1930 to the present the British approach to D&T has gone through many changes. The forces behind those changes have included economic, political, cultural, and educational pressures. A review of the history of those changes can illustrate for the reader how volatile the process of making curricular decisions can be in a democratic society where every individual, group, or agency has a vested interest (See Atkinson, 1990; Benson, 2009; Eggleston, 2001; Hope, 2004; Raizen, Sellwood, Todd, & Vickers, 1995).

Eggleston (2001) described the structure of the program this way: "Design and Technology is unique in the school curriculum. It is the one subject directly concerned with the individual's capacity to design and make, to solve problems with the use of materials and to understand the significance of Technology" (p. 23). This definition of D&T provides the basic components of what makes it a rich curriculum for helping students to grow and develop into active participants in a technological world. First, it is student centered in that it addresses "the individual's capacity." Second, it is action oriented in that it is focused on the verbs of "design,' "make," and "solve." Finally, it involves the use of both the hands and the brain as inferred through the words "design,' "make," "solve," "materials," and "understand." D&T also brings other important ingredients into the mix of what makes it a rich curriculum. These other components include the use of student driven research, student made decisions about designs, and student generated portfolios/documentation of what was learned. Furthermore, the social/cultural values that were so important to members of the progressive line of industrial arts at the turn of the 20th century are also explicitly endorsed in D&T. The Department for Education and Employment/Qualifications and Curriculum Authority addressed the broad ranging role of D&T in the National Curriculum of the UK (as cited by Hope, 2004) by writing

> Design and technology prepares pupils to participate in tomorrow's rapidly changing technologies. They learn to think and intervene creatively to improve quality of life. The subject calls for pupils to become creative and autonomous problem solvers, as individuals and members of a team. They must look for needs, wants and opportunities and respond to them by developing a range of ideas and making products and systems. They combine practical skills with an understanding of aesthetics, social and environmental issues, function and industrial practices. As they do so, they reflect on and evaluate present and past design and technology, its uses and effects. Through design and technology, all pupils can become discriminating and informed users of products, and become innovators. (Hope, 2004, p. 17)

What then does it mean to prepare "pupils to participate in tomorrow's rapidly changing technologies?" Based on a three-year study on the 'Design Skills for Work,' Kimbell, Saxton, and Miller (2000) wrote that the resulting benefit to D&T students from participation in the program was the acquisition of what they referred to as "design capability," which they then described as

> a set of strategic skills that our students acquire through design experiences:
>
> - the ability to unpack and get to grips with highly complex tasks;
> - the ability to recognize and optimize value positions;
> - the ability to model alternative futures;
> - the ability to cope with risk;
> - the ability to manage complexity. (p. 127)

The ideals of the D&T curriculum in The United Kingdom are present in many of the other design and technology or technology education curriculums around the globe. Several books that can provide the reader with greater detail on a variety of programs include *International Handbook of Research and Development in Technology Education* (Jones & de Vries, 2009), *International Handbook of Technology Education: Reviewing the past twenty years*? (De Vries & Mottier, 2006), and the 55th yearbook of the Council on Technology & Engineering Teacher Education entitled *International Technology Teacher Education* (Williams, 2006). These books, a variety of professional journals, including *Design and Technology: An International Journal* (http://ojs.lboro.ac.uk/ojs/index.php/DATE/issue/archive), and multiple websites including IDATER Archive (https://dspace.lboro.ac.uk/dspace-jspui/handle/2134/954) can provide the reader with access to descriptions of the nature of creativity and design within the technology education or design and technology curriculums of countries from around the world.

The brevity of this section of the chapter should not be interpreted as a diminishment of the importance of what can be learned by looking at how creativity and design manifests itself in the technology education curriculums around the world. Wright (1993), in his critique of D&T, acknowledged that "we need to learn from each other. Every country that has technology education programs have (*sic*) something to offer curriculum developers" (p. 67).

THE FUTURE OF CREATIVITY AND DESIGN WITHIN THE CURRICULA OF TECHNOLOGY EDUCATION

One's future is built upon a foundation of one's past. In this chapter the past of humankind, technology education, and design and technology have been briefly examined. Each of these facets of the story of creativity and design within technology and technology education can provide its own contributions to enriching the learning experiences of students. I believe it is significant that an increasing number of writers in education and the general media are beginning to comment on the need for creativity and designerly experiences in the general education curriculum. One of those writers is Pink (2005) who's persuasive argument was that the thinking tools of the industrial and information age are no longer effective for what he referred to as the "Conceptual Age" (p. 2). Pink asserted that in the conceptual age a successful individual will need to develop six additional senses that have been underplayed or ignored in previous ages. Those six senses were

1. Not just function but also Design.
2. Not just argument but also Story.
3. Not just focus but also Symphony.
4. Not just logic but also Empathy.
5. Not just seriousness but also Play.
6. Not just accumulation but also Meaning. (pp. 65-66)

The paradigm shift Pink is recommending is one that should be relevant to all of education not just technology education. Similar forecasts have come from others in the field including Lewis, Zuga, and myself. Outside of the field, other well-known writers such as Florida

(2007, 2002) and Friedman (2006) have contributed to the conversation in the media about the importance of creativity and designerly thinking.

From the perspective of methodology, technology education could also be finding itself in the position of being a leader in the dynamics of using active engaged approaches to teaching and learning. Terms like "creativity," "problem-based learning," "project-based learning," or "inquiry-based learning" are now starting to appear in efforts to address how to meet standards for core subjects such as mathematics, science, the humanities, and language literacy. Unlike most other countries, the United States does not have a national curriculum. As a result, the most accepted set of standards at this time are the Common Core State Standards, a cooperative arrangement among a majority of the states (Markham, 2012). Regardless of what the methodology is called, the basis of the approach that is being advocated in the literature to help meet these standards is the hands-on, applied learning techniques that are now and have been at the core of technology education for over a hundred years.

The future of technology education, technology and engineering education, or design and technology will be dependent on how much value the curriculums add to the educational experience of young people. I believe that the plans for cultural progress that have been written about by writers such as Pink, Florida, and Friedman are sound and obtainable and that technology education can and should play a vital role toward achieving that progress. I also believe that our profession has built a strong foundation upon which to build this new paradigm of creativity and design. Leaders such as Bonser and Mossman, Dewey, Maley, and a host of others around the world have helped to build that foundation. It is up to those of us currently in the profession to continue to advocate the importance of creativity and design as the primary tools for the study of technology.

CONCLUSIONS AND SUMMARY

The dinner I alluded to in the introduction of this chapter was both physical (the food I ate) and metaphorical (the ambiance of the restaurant). Both of those meals were at least satisfying but they still left me wanting more. The food was fine; it satisfied my basic hunger. The surroundings were engaging, interesting, and pleasant to look upon. The character of the environment was also satisfying at a basic level, after all the artifacts were only intended as decorations and not as lessons in American history. However, I have had meals of both types that have made me feel pleasure and fulfillment above and beyond the mere satisfaction of my physical and intellectual needs. Those types of meals are gratifying. It is toward this type of gratification that creativity and design should be used as the catalyst for changing technology education (and by extension technology and engineering education) into a subject area in which all students will want to be participants, a place where all can find intellectual, physical, and personal fulfillment and gratification.

In the chapters that follow the reader will find a variety of perspectives on the various aspects of creativity and design. The writers have been selected for their respective chapters because of the expertise they possess with their given topic. This mix of experts was selected to provide the reader with a sense of the richness creativity and design can add to technology education. One yearbook alone cannot possibly cover all of the many aspects of creativity and design. However, the editors and writers all hope that you the reader will find within these pages some kernels of insight that will spark you toward further investigation and use of creativity and design in your classroom, laboratory, or studio. This yearbook is not a cookbook for success with using creativity and design in technology education but it can be thought of as an important ingredient for helping to transform technology education into a gratifying meal for students and teachers alike.

REFLECTIVE QUESTIONS

1. How would the use of the word "designerly" as a normal part of a technology educator's vocabulary affect how he or she thinks about and describes technology education?
2. How could technology education programs fully address and promote the relationship between the hand and the brain toward learning?
3. How can the history of technology be used to encourage interdisciplinary studies of creativity and design?
4. What lessons can be learned from the history of technology education about the successful applications of creativity and design that can now be used in the transition to technology and engineering education?
5. What lessons can be learned from technology education curriculums around the world, such as Design and Technology in the UK, about the successful applications of creativity and design?

FOOTNOTE

[1]Benedetto Croce (1866-1952) was an Italian philosopher and social critic. Additional information on his life story and a brief listing of articles about his ideas can be found at http://www.britannica.com/EBchecked/topic/143635/Benedetto-Croce

REFERENCES

Atkinson, S. (1990, Fall). Design and technology in the United Kingdom. *Journal of Technology Education*, *2*(1), 1-12.

Bennett, C. A. (1937). *History of manual and industrial education 1870-1917*. Peoria, IL: Charles A. Bennett.

Benson, C. (2009). Design and technology: A 'new' subject for the English National Curriculum. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 17-30). Boston: Sense.

Bonser, F. G. & Mossman, L. C. (1931). *Industrial arts for elementary schools.* New York: Macmillan.

Bronowski, J. (1973). *The ascent of man*. Boston: Little, Brown and Company.
Brown, S. (Speaker). (2008). *Stuart Brown says play is more than fun* [Video webcast]. Retrieved from http://www.ted.com/talks/lang/en/stuart_brown_says_play_is_more_than_fun_it_s_vital.html
Bryant, V. (n.d.). The origins of the potter's wheel. *Ceramics Today*. Retrieved from http://www.ceramicstoday.com/articles/potters_wheel.htm
Burke, J. (1996). *The pinball effect*. Boston: Little, Brown and Company.
Burke, J. (1985). *The day the universe changed*. London: British Broadcasting Corporation.
Burke, J. (1978). *Connections*. Boston: Little, Brown and Company.
Burke, J. & Ornstein, R. (1995). *The axemaker's gift: A double edged history of human culture*. New York: Gosset/Putnam.
Cardwell, D. (1995). *The Norton history of technology*. New York: W. W. Norton.
Cochran, L. H. (1970). *Innovative programs in industrial education*. Bloomington, IL: McKnight and McKnight.
Craft, A. with Dugal, J., Dyer, G., Jeffrey, B., & Lyons, T. (1997). *Can you teach creativity?* Nottingham: Education Now.
Cross, N. (2007). *Designerly ways of knowing*. Boston: Birkhauser Verlang AG.
DeVore, P. (1980). *Technology: An introduction*. Worchester, MA: Davis.
De Vries, M. (2009). The developing field of technology education: An introduction. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 1-9). Rotterdam, The Netherlands: Sense.
De Vries, M. J. & Mottier, I. (Eds.). (2006). *International handbook of technology education: Reviewing the past twenty years.* Rotterdam, The Netherlands: Sense.
Eggleston, J. (2001). *Teaching design and technology* (3rd ed.). Buckingham: Open University.
Florida, R. (2007). *The flight of the creative class: The new global competition for talent*. New York: Collins.
Florida, R. (2002). *The rise of the creative class*. New York: Basic Books.

Friedman, T. (2006). *The world is flat: A brief history of the twenty-first century*. (2nd ed.). New York: Farrar, Straus and Giroux.

Gardner, D. P., Larsen, Y. W., Baker, W. O., Campbell, A., Crosby, E. A., Foster, Jr., C. A. . . . Wallace, R. (1983, April). *A nation at risk: The imperative for educational reform*. Washington, DC: U.S. Government Printing Office.

Hellmold, A. (2001). *Potter's wheel, Egypt, 2400 BCE*. Retrieved from http://www.smith.edu/hsc/museum/ancient_inventions/potterwheel2.html

Herschbach, D. R. (2009). *Technology education: Foundations and perspectives*. Homewood, IL: American Technical Publishers.

Hoffecker, J. F. (2011). *Landscape of the mind: Human evolution and the archaeology of thought*. New York: Columbia University Press.

Hope, G. (2004). *Teaching design and technology 3-11: The essential guide for teachers*. London: Continuum.

Hutchinson, J. & Karsnitz, J. (1994). *Design and problem solving in technology*. New York: Glencoe/McGraw-Hill.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology*. Reston, VA: Author.

Johanson, D., Johanson, L., & Edgar, B. (1994). *Ancestors: In search of human origins*. New York: Villard.

Jones, A. (2009). The development of technology education internationally. In A. T. Jones & M. J. de Vries (Eds.), *International handbook of research and development in technology education* (pp. 13-16). Rotterdam, The Netherlands: Sense.

Jones, A. & de Vries, M. J. (Eds.). (2009). *International handbook of research and development in technology education*. Rotterdam, The Netherlands: Sense.

Kimbell, R., Saxton, J., & Miller, S. (2000). Distinctive skills and implicit practices. In J. Eggleston (Ed.), *Teaching and learning design and technology: A guide to recent research and its applications* (pp. 116-133). London: Continuum.

Kranzberg, M., & Pursell, C. W. (1967). *Technology in western civilization* (Vols. 1-2). New York: Oxford University Press.

Lewis, T. (2005, Fall). Creativity—A framework for the design/problem solving discourse in technology education. *The Journal of Technology Education, 17*(1), 35-52.

Lewis, T., & Zuga, K. (2005). *A conceptual framework of ideas and issues in technology education*. Columbus, OH: Technology Education Program, Science, Technology, Engineering, and Mathematics Section, School of Teaching & Learning, The Ohio State University, College of Education & Human Ecology (Supported through National Science Foundation Grant No. ESI-0138671).

Lindbeck, J. (1963). *Design textbook*. Bloomington, IL: McKnight and McKnight.

Markam, T. (2012, February 21). Project-based learning and common core standards [Web log post]. Retrieved from http://whatworks.wholechildeducation.org/blog/project-based-learning-and-common-core-standards/

Mayer, B., & Gray, R. (1993). *In the Arts & Crafts style*. San Francisco: Chronicle.

Micheels, W. J., & Sommers, W. S. (1958). *The Minnesota Plan for industrial arts teacher education*. Bloomington, IL: McKnight and McKnight.

Obniski, M. (June 2008). *The Arts and Crafts movement in America*. In *Heilbrunn Timeline of Art History*. New York: The Metropolitan Museum of Art, 2000–2011. Retrieved from http://www.metmuseum.org/toah/hd/acam/hd_acam.htm

Osburn, B. N. (1948). *Constructive design*. Milwaukee: Bruce.

Pink, D. (2005). *A whole new mind: Moving from the information age to the conceptual age*. New York: Riverhead.

Pye, D. (1978). *The nature and aesthetics of design*. Bethel, CT: Cambium.

Raizen, S. A., Sellwood, P., Todd, R. D., & Vickers, M. (1995). *Technology education in the classroom: Understanding the designed world*. San Francisco: Jossey-Bass.

Schick, K., & Toth, N. (1993). *Making silent stones speak: Human evolution and the dawn of technology*. New York: Simon & Schuster.

Scobey, M. M. (1968). *Teaching children about technology*. Bloomington, IL: McKnight and McKnight.

Snyder, J., & Hales, J. (1981). *Jackson's Mill industrial arts curriculum theory: A base for curriculum derivation*. Charleston, WV: West Virginia Department of Education.

Warner, S. A., Morford Erli, L., Johnson, C. W., & Greiner, S. W. (2007, Spring). Identifying the paradigm of design faculty in undergraduate technology teacher education in the United States. *The Journal of Technology Education, 18*(2), 68-87.

Warner, S. A., & Morford, L. L. (2004, Spring). The status of design in technology teacher education in the United States. *The Journal of Technology Education, 15*(2), 33-45.

Warner, S. A. (2000). *The effects on student's personality preferences from participation in Odyssey of the Mind* (Unpublished doctoral dissertation). West Virginia University, Morgantown, WV.

Warner, W. E. [with Gary, J. E., Gerbracht, C. J., Gilbert, H. G., Lisack, J. P., Kleintjes, P. L., and Phillips, K.]. (1953). *The industrial arts curriculum: Development of a program to reflect American technology* [Proposal]. Columbus, OH: Epsilon Pi Tau. (Original work presented at the American Industrial Arts Association Conference in 1947)

Wilber, G. O. (1948). *Industrial arts in general education*. Scranton, PA: International Textbook.

Williams, P. J. (Ed.). (2006). *Council on Technology Teacher Education 55th yearbook: International technology teacher education*. New York: Glencoe/McGraw-Hill.

Williams, T. I. (1987). *The history of invention: From stone axes to silicone chips*. New York: Facts on File.

Wilson, F. R. (1998). *The hand: How its use shapes the brain, language, and human culture*. New York: Vintage.

Wright, R. T. (1993, Spring). British design and technology: A critical analysis. *The Journal of Technology Education, 4*(2), 58-68.

Woodward, C. (1887). *The manual training school*. Boston: D. C. Heath.

Defining Creativity and Design

Chapter 2

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We humans use creativity and design to solve a wide variety of challenges. From artist to artisan, from engineer to photographer, people create solutions that involve intuition and reason to varying degrees. Over the past century those who employ creativity and design have become increasingly specialized but perhaps more importantly, have found their ability to design to be increasingly valuable for solving contemporary complex problems in a comprehensive and imaginative way. While the artist, artisan, and engineer approach the creative process from different perspectives, they share common themes. Students can certainly benefit from learning about the similarities and differences among the various approaches to creativity and design. In fact, a general approach to creativity and design can be considered an important tool for everyone.

DEFINING TERMS

The purpose of this chapter is to provide the reader with working definitions and elaborations of key concepts. These definitions should be helpful toward providing a better understanding of the relationships among these concepts and the teaching of technology. The first definitions will deal with the contexts of technology and engineering. The rest of the chapter will define and expand on the concepts of creativity, design, art, craft, and other related terms.

Technology and Engineering. The relationship between technology and design (both architectural and engineering) is one that is so tightly bound together that it could be described as symbiotic.

Pearson and Young (2002) defined technology as “the process by which humans modify nature to meet their needs and wants” (p. 13). DeVore’s (1980) earlier definition of technology provided elaboration by stating that technology is “the creation and utilization of adaptive systems including tools, machines, materials, techniques and technical means and the relation of the behavior of these elements and systems to human beings, society and the civilization process” (p. 4). For most of human history the processes of developing and refining technologies were acts of trial and error, keen observation of natural phenomena, and serendipity. Harrisberger (1982) stated

> Early technical progress in engineering was almost totally accidental. There was no rationale and no fundamental knowledge of nature. People continued to reconstruct these fortuitous accidents methodically and exactly throughout the years in order to preserve the results that were stumbled upon. (p. 5)

From the perspective of our current place in history, “Engineers are the professionals who are most closely associated with technology” (ITEA, 2000, p. 23). What distinguishes most of the technological developments of the modern world from those of the past is the involvement of engineering in the process. Petroski (1992) cited an official definition of civil engineering used by the American Society of Civil Engineers to identify what all forms of engineering specifically brings into the process of technological development. That definition stated:

> Civil engineering is the profession in which a knowledge of the mathematical and physical sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the progressive well-being of mankind in creating, improving and protecting the environment, in providing facilities for community living, industry and transportation, and in providing structures for the use of mankind. (p. 210)

From this perspective, engineering makes the process of technological development a purposeful, informed, designed act of technological creation.

Creativity. Creativity is one of those terms with many meanings. Treffinger, Young, Selby, Shepardson, and Center for Creative Learning Sarasota, Florida (2002, December) identified previous literature reviews that produced a substantial number of definitions for creativity. Their reasoning for why the literature produced over 100 definitions for this word is because "creativity is complex and multi-faceted in nature" (p. 5). To showcase the variety of definitions they provided samplings of definitions for creativity from 14 noted writers/researchers on this subject (see Table 1). A review of the definitions in Table 1 shows that they can be segregated into two broad categories: definitions that look at the behavior, actions, or characteristics of the person performing the creative act or the end product or outcome of the creative act. Tardiff and Sternberg's (1988) view of creativity as being processes, persons, products, and places, or as problem domains and socially organized fields of enterprise is complementary of the findings of Treffinger et al. on the variety of definitions for creativity. Mayer's (1999) identification of originality and usefulness as key attributes of creativity provides further focus on the unique nature of what is produced, which can be either an artifact or an idea.

Table 1. Sample Definitions of Creativity

Sample Definitions	**Emphasis in Definition**	**Primary Focus**	**Implications for Assessment** ***Identify creativity through:***
Fromm, Khatena, MacKinnon	Person	Characteristics of highly creative people	Assessment of creative personality traits
Gordon, Guilford, Mednick, Torrance, Treffinger et al., Wallas	Cognitive process or operations	Skills involved in creative thinking or in solving complex problems	Testing for specific creative thinking and problem solving aptitudes or skills
Maslow, Rogers	Lifestyle or personal development	Self-confidence, personal health and growth; self-actualization; creative context or setting	Assessing personal adjustment, health, and self-image; assessing the climate that nurtures or inhibits creativity
Gardner, Khatena	Product	Results, outcomes, or creative accomplishments	Assessing and evaluating products or demonstrated accomplishments
Amabile, Rhodes	Interaction among person, process, situation, and outcomes	Multiple factors within specific contexts or tasks	Assessing multiple dimensions in a profile, with various tools

Source: "Assessing Creativity: A Guide for Educators" by D. J. Treffinger, G. C. Young, E. C. Selby, C. Shepardson, & Center for Creative Learning Sarasota, Florida (2002, December). Used with permission of The National Research Center on the Gifted and Talented.

Looking at creativity from another perspective, Csikszentmihalyi (1996) placed it within the context of a systems model, a context that should be familiar to the typical technology educator. Csikszentmihalyi's description of this systems model perspective on creativity was as follows:

> Creativity can be observed only in the interrelations of a system made up of three main parts. The first of these is the *domain*, which consists of a set of symbolic rules and procedures. Mathematics is a domain. . . . Domains are in turn nested in what we usually call culture, or the symbolic knowledge shared by a particular society….
>
> The second component of creativity is the *field*, which includes all the individuals who act as gatekeepers to the domain. It is their job to decide whether a new idea or product should be included in the domain. . . .
>
> Finally, the third component of the creative system is the individual *person*. Creativity occurs when a person, using the symbols of a given domain such as music, engineering, business, or mathematics, has a new idea or sees a new pattern, and when this novelty is selected by the appropriate field for inclusion into the relevant domain. . . .
>
> So the definition that follows from this perspective is: Creativity is any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one. And the definition of a creative person is: someone whose thoughts or actions change a domain, or establish a new domain. (pp. 27-28)

Regardless of which of the many definitions of creativity we choose to accept as our own, we all face challenges that inspire us to find solutions through the process of invention or that prod us to address the challenge through other creative expressions. It helps to think of what we do when facing such challenges as a *response* rather than an answer or a solution. This approach has several advantages. A response is broader than a product or artifact. For example, some responses do not involve tangibles but might be processes. Those who face challenges more imaginatively, who think "outside the box" tend to come up with better responses. Creative problem solving is critical to any game plan, whether done by a CEO in response to a business challenge, a division commander in response to a military push, an industrial engineer in response to a manufacturing challenge, or an architect in response to a housing need (von Oech, 1998).

Words like *artist* and *genius* carry heavy baggage. Those characterized as such are often seen in society as constituting an elite fraternity, even a secret cabal, of gifted individuals whose creations may or may not be understood, but either way are not to be questioned by those less enlightened people from outside the fraternity. Such people are generally admired for their creativity, their ability to come up with innovative responses to challenges major and minor. But, they are also often seen as people who are a little strange, who just do not think the way the rest of us do (Boden, 1991; Kneller, 1965; Pinker, 1997).

But how do they do it? Where does creativity come from? Does one have to be born with the ability? Can people create even when they are not particularly creative (at least so far as they know)? Creative work is often described as a sort of "black box" process that those who use it often profess not to understand. Some equate process with logic, and thus think that identifying a process will override its intuitive component, thereby destroying its power. While this fear is misplaced, it leads the rest of us to assume that we cannot do that thing that they do so well – come up with creative solutions to functional problems – to "think outside the box".

There is an interesting difference between traditional concepts of intelligence, normally associated with convergent thinking, and creativity, which is normally associated with divergent thinking; creative people manage to come up with multiple solutions where others fail to see even one (Gardner, 1993). Motivated by his own interest and experience with art, Gardner explored creativity in his book *Creating Minds* by examining seven creative individuals. Anyone aware of his theories about intelligence would not be surprised to learn that he concluded that creativity has many facets and can find its expression is many ways, certainly not just through art.

In the final chapter of the book *The Nature of Creativity* Tardif and Sternberg (1988) summarized the findings from the various chapter authors, all leading experts on creativity. They concluded that the creative thought process involves

- time (i.e., even if the creative process is thought to arguably involve a single flash of insight, a gestation process follows that involves refinement);
- transformation of external world and internal representations by forming analogies and bridging conceptual gaps;
- constant redefining of the problem;

- applying recurring themes and recognizing patterns and images of wide scope to make the new familiar and the old new;
- non-verbal modes of thinking; and
- tension between tradition and breaking new ground, the tension of having several competing ideas, and the battle between unorganized chaos and the drive to higher levels of organization.

Expressions of creativity can be broadly categorized as being either *abstract* or *applied* in nature. Abstract creativity results in self-expression that is usually described as artistic. However, technology education is more concerned with applied creativity. Applied creativity is defined by its effects on the natural and human made environments and gauged by the impacts it has on the uniqueness, efficacy, and variety of the solutions it generates.

Creativity is like a muscle that can be strengthened and developed. A designer can begin the process of generating responses (i.e., developing solutions) with only a rudimentary understanding of the challenge. However, he or she can also use the design process to get to a more complete understanding of the challenge. The designer can also wait until the challenge is fairly well explored through logic before starting to apply creativity. Regardless of which approach is used, this process of generating alternative responses is generally referred to as *brainstorming*.

Brainstorming gives us a way to increase the odds of finding inspiration. Inspiration may be provided by divine intervention, but generally, and especially with practice, can be provided by and traced back to some factoid or observation or recognition that was noticed, on some level, during fact-gathering, during the logical, left-brained part of the design cycle. Sometimes a designer will come up with an idea and not realize where it came from at first, only to recognize its source later on as something he or she originally noticed while visiting a project site or in talking to a projects' future users or in something glanced in a magazine the weekend before. It may come across as inspiration for any of several reasons. The underlying or triggering fact may have been noticed only peripherally and may not have even registered consciously at the time it was gathered. Or it may have registered consciously, but with little or no sense of how it might be related to the problem at hand. Or it might have registered consciously, with some sense of how it might inform a solution, but without much of an idea of how it could be integrated with other factors in developing a complete, holistic, integrated solution.

Regardless of where the idea came from, it came from somewhere. The critical point is that it found its way into at least one proposed response – it was put on the table for consideration. And except for occasional and unintended moments of inspiration, what got it on the table was the process of brainstorming. Those who are not experienced in the design process (including "designers" who do not understand how they do what they do, but manage to do it without consciously using a design process) may not brainstorm or may not recognize their brainstorming efforts for what they are, and therefore tend to see all good ideas as being rooted in inspiration. Brainstorming is not critical, but without it there are far fewer options to work with. And with fewer options, it is less likely that an ideal one will emerge.

So how do designers use brainstorming to supplement or even to generate inspiration? They do so by letting go, by looking beyond the immediate goal of trying to solve problems. Being creative starts with opening one's mind. Often, the best answer is not immediately seen as an outgrowth of the problem, but is seen as only tangentially or indirectly related. So it is critical to "think outside the box" to look beyond responses that are clearly in the realm of possible solutions. One needs to step back from the immediate task, to be non-judgmental as well as inefficient, in the short term at least. Brainstorming demands a willingness to:

- make mistakes on the way to a good solution.
- delay solving a problem while considering multiple alternatives.
- accept that although being creative is fun, when used this way it is a very serious undertaking.

In addition, it requires an understanding that creativity is only part of the design process, which requires alternate use of left (logical) and right (intuitive) brained thinking, with transition periods as needed in between.

The generation of many ideas to solve a problem is as old as human ingenuity. However, the process of brainstorming was named and formally structured by Alex Osborn. Osborn (1953), who was an advertising executive in search of a technique for developing lots of ideas, first started using "organized ideation" (p. 80) as early as 1938.

Though commonly thought of as a group activity, Osborn advocated the use of the brainstorming approach for both individual and group ideation. The basic rules for brainstorming that Osborn identified were

1. *Criticism is ruled out.* Adverse judgment of ideas must be withheld until later.
2. *"Free-wheeling" is welcomed.* The wilder the idea, the better; it is easier to tame down than to think up.
3. *Quantity is wanted.* The greater the number of ideas, the more the likelihood of winners.
4. *Combination and improvement are sought.* In addition to contributing ideas of their own, participants should suggest how ideas of others can be turned into better ideas; or how two or more ideas can be joined into still another idea. (p. 84)

Further guidelines advocated by Osborn (1953) for running a successful group brainstorming session included the ideal group size of 12 participants (p. 87), group brainstorming is a supplement of the individual brainstorming process (p. 80), there needs to be a written "reportorial" list made of the ideals generated (pp. 84-85), and an appropriately trained group leader who would facilitate the brainstorming session (p. 237).

Since 1958 there has been a great deal of controversy over the effectiveness of brainstorming as a technique for having a group of people generate lots of creative ideas. The original source of this controversy was a study completed at Yale University (Taylor, Berry, & Block, 1958) that asked the question "does group participation when using brainstorming facilitate or inhibit creative thinking" (p. 23). Unfortunately, as Vehar (2010) indicated, the results from the Yale study have been repeatedly misinterpreted to mean that brainstorming across the board does not work. Vehar summarized the problems of the original Yale study and the misinterpretation of what constitutes brainstorming by stating

> [Over the years] several studies [have] use[d] the same misguided approach that the Yale study did, which is to say that they don't use a trained facilitator to direct the group. Brainstorming is a specific tool with specific guidelines (defer judgment, etc.) that are enforced by a facilitator who guides the group's thinking.
>
> What many people mistakenly call "brainstorming" is in fact just "a bunch of people sitting around firing off and shooting down

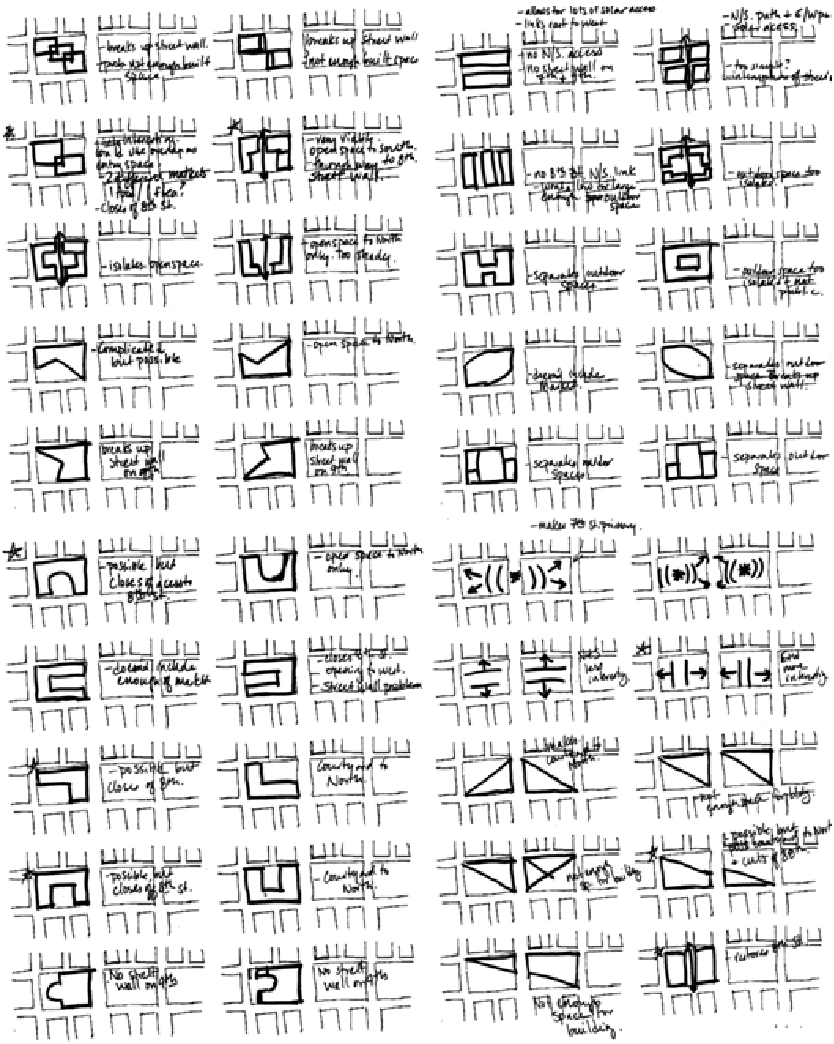
ideas." Let's call that "skeet-shooting." And on that we can agree: working individually will work better than skeet-shooting in a group. (para. 8-9)

Beyond the mechanics of the process and the controversy, brainstorming is the task of generating, without judgment, copious alternatives from subconscious knowledge (i.e., information known at an intuitive level). It is the fundamental basis of creativity, open and free. The goal of brainstorming is to push the limits, to ask nothing, but just to generate. One could interrupt the process of brainstorming by asking "does this make sense," but that would interrupt its flow, impairing its effectiveness, so one leaves that question to be asked later. Logically, there may be lots of reasons "why not" that can censor creativity and lead to the rejection of a potential solution before it has had a chance to be truly considered. Often, what so clearly seemed infeasible or problematic turns out, upon more careful examination, to be quite feasible. For these reasons, even subconscious judgment of ideas during brainstorming is counterproductive.

As an example of individual brainstorming, the sketches shown in Figure 1 (next page) represent one page containing forty alternative site plans generated by an architecture student exploring different ways to configure a new building on an existing site (Vanderdray, 2006). She kept going until she had filled eight pages with about two hundred options in less than an hour. Every alternative was feasible to the extent that it represented a building of about the right floor area and fit within the confines of the block.

But given those two key parameters, which could easily be understood at an intuitive level, anything that complied with them was worth a look. Were angled walls worth considering? Yes, as were curved walls or walls of any other shape. Were both symmetrical solutions worth considering? Yes, as were asymmetrical solutions, simple and complex solutions, and balanced and unbalanced solutions.

Figure 1. Tapping the Subconscious Through Brainstorming



Source: "Healthy Bodies, Healthy Buildings: A Farmer's Market and Cooking School for Washington, DC" by L. Vanderdray (2006).

Notice in this example how each sketch used only a few lines, supplemented with a few words serving to capture the basic idea for later on, when the student returned to evaluate and select the stronger choices from among her many options. This brevity of notation allowed the ideas to be recorded almost as fast as they were imagined, so that the brainstorming mind was made available again very quickly to generate more ideas rather than lingering on any one idea. Will any one of these two hundred ideas be the seed of genius from which a great design will come? There is no guarantee, but certainly the odds of that being true is far greater than it would have been if only ten ideas had been generated.

In another example, it is often said that great wedding albums are the result of not only a photographer with a great eye, but also of a photographer who takes a lot of photos. It is doubtless true that one can make a far better forty-photo wedding album from five thousand images than from three hundred. And a photographer who hesitates too much, who thinks for too long about whether a particular shot is worth taking, puts intellect above intuition, risks losing the opportunity to get a particular shot. This caveat is not to suggest that good photographers randomly press the shutter. Rather, they use their intuitive understanding of the elements of a good photo to manipulate the interaction of the events taking place, their position, the lighting, and the composition in the viewfinder to raise the odds that any photo they take will be a quality image. But, they do their choosing and editing after the event is over, once they have finished creating and start editing.

Individual brainstorming has many of the characteristics of play. Stuart Brown (2009) identified the properties of play as

- Apparently purposeless (done for its own sake),
- Voluntary,
- Inherent attraction,
- Freedom from time,
- Diminished consciousness of self [an "in the zone" experience],
- Improvisational potential [for thinking and doing], and
- Continuation desire [toward the experience] (pp. 16-18).

Like play, brainstorming is best done with toys rather than words or numbers. When in this mode, designers act, they *do,* rather than talk or write. There is something about movement, about action, that allows things we know subconsciously to express themselves. This phenomenon is why architects learn to trust their hands. Sometimes, architects will just start drawing, and in doing so, find that their hands document design alternatives that their minds did not consciously know they were thinking. Artists will often play with clay or paint or stone just to prime their ability to generate inspiration. Mechanics might just start arranging or cutting or assembling parts with no fixed idea of what they are trying to get out of the process. Athletes and dancers can use bodily movement to help them brainstorm. Musicians can hum, sing, or play instruments to help them.

To the extent that someone using the design process can figure out, on a conscious level, the subconscious information that led to his or her insight, so much the better. That knowledge can make it easier in the future to repeat the feat of "inspiration at will", and at least helps to satisfy what otherwise may be a gnawing uncertainty about whether brainstormed ideas are based in valid issues and legitimate knowledge.

Note that for the subconscious mind to use the information it "knows," that information needs to be known to the subconscious. If it was initially received or registered there, all is fine. But if a student first becomes aware of an important factor on a conscious or intellectual level, as the result of fact gathering or experimentation, it needs to be "forgotten", to be registered in the subconscious. As mentioned above, achieving this movement is one of the critical roles of the transition time inserted between cycles of logic and intuition.

So is creativity simply the product of a large number of alternatives informed by intuition? What about artistry? What about inspiration? While it is true that bolts of inspiration can sometimes strike, odds are greatly increased if one takes the time to increase the field of possibilities through brainstorming. If a truly inspiring solution is not among the ones being considered, it cannot be selected.

And what of the idea of creativity restrained only by some intuitive understanding of the goals, without intellectual constraints? What is the point of generating options that in the end will prove to be "bad ideas?" Is that not an inefficient use of time? Designers will respond that it is actually a very efficient use of time, because it is far more expeditious to unbundle idea generation from idea evaluation than to try to do them simultaneously. Brainstorming is a very powerful exercise, and left free to do its work, is so efficient in generating alternatives that one can afford to throw most of the ideas in the scrap heap before one would have to worry about using time inefficiently.

It is also critically important to feed the intuition before starting to brainstorm, or the alternatives generated will be meaningless. This might be thought of as "stoking" the process. Stoking involves gathering information, analyzing it, and extracting the implications of the analysis for the challenge at hand. Once this is done, it must be moved from the conscious mind to the subconscious, to influence brainstorming in an unselfconscious way. We will come back to this idea later, after we finish exploring creativity and brainstorming.

How can the creative side be freed to do its work? It requires letting go of the intellect, of being willing to suspend being "responsible" and "focused". For Americans, perhaps the difficulty is related to having frontier and Puritan roots. Creativity is closely related to play, and we tend to do less of both as we get older, as we grow up. But this idea of play, truth be told, is what drives designers in their passion for what they do. Allowing the brain to run at full throttle, without restraint, without thinking "oh, that won't work or that's dumb" is incredibly addictive. But most of us have never experienced that rush, because we cannot stop being practical, cannot stop thinking about what "can" and "cannot" work. But it is only when we do allow ourselves to forget, that we unleash the full power of our minds, though the power of creativity when used as part of the design process.

Eventually one must ask, "does this make sense?" Once a list of response alternatives is generated it must usually be edited down to a single response since usually only one response can be implemented. To do that, the positive and negative evidence regarding the advantages and disadvantages of potential responses must be applied to the alternatives that were generated at the subconscious level. This requires that the alternative solutions be documented, be made tangible, so they can be recalled and assessed once the brain has emerged from its intuitive mode and, to some extent, forgotten some aspects of the full idea that had been envisioned. Concepts can be made tangible with a few short scribbled notes, through sketches, models, simulations, or with any number of other means of representation or expression, many of which are seen as evidence of creativity, even though they are really only but one step along the process of design.

Design. Creativity, as discussed, is an essential element in the overall process of design. Though the word *design* can be both a noun and a verb, this chapter focuses on design as a verb. This focus is intentional because, ideally, technology education uses the end product of the design process (a noun), as simply a means to teaching students how to do the process (a verb). The *American Heritage Dictionary of the English Language* defined design as a verb: "to formulate a plan for; devise" (Design, 2009). The focus in this chapter is more about teaching people how to design rather than what to design. Fundamentally, design is one of several processes people can use when making decisions. Design harnesses both intellect and intuition to solve challenges too complex to be solved by either one alone. The ability of the design process to work when addressing highly complex challenges is what informs it as a process, and what makes it so versatile and relevant to contemporary problems in this era of globalization. The key, defining characteristic of design is the fact that designers think holistically, using both the left and right sides of their brain. Design combines creative elements and processes, such as brainstorming, with evaluative editing in repeated cycles to get increasingly close to an ideal solution, especially when stoked occasionally with supplemental information.

Design and Technology. Design is categorized as both a part of technology and a broader unifying theme for multidisciplinary education. The British were leaders in the adoption of design as a fundamental part of technology education. In the 1980s, curriculum development efforts eventually resulted in the creation of three textbooks for craft, design, and technology (CDT). One of them, *Design and Realisation* contained this explanation of design:

> Designing is an activity which uses a wide range of experiences, knowledge, and skills to find the best solution to a problem, within certain constraints.
>
> Designing is a creative activity. You may often use known facts or solutions, but the way to combine these to solve your own particular problem requires creative thinking.
>
> Design is far more than just problem solving. It involves whole process of producing a solution from conception to evaluation. This includes elements such as cost, appearance, styling, fashion and manufacture (Breckon, 1988, p. 2).

In 1994, Americans Hutchinson and Karsnitz offered a straightforward definition of design:

> Design is *the planned process of change*. Instead of something changing by accident, design demands that we change so that we end up with the results we want. It also means that we attempt to minimize trade-offs and control risk. Technology is all about design. (p. 18)

The International Technology Education Association (2000) made a critical contribution to the field by identifying design as an essential underpinning of technology. “Design is regarded by many as the core technological problem-solving process of technological development. It is as fundamental to technology as inquiry is to science and reading is to language arts (p. 90).

Design as a Process. Breitenberg (2003) described design as more than a tool used by various practitioners but as a discipline in its own right. He reveals his belief in the interdisciplinary nature of the design discipline in recounting the accomplishments of Raymond Loewy who "was trained as a fashion illustrator, designed a steam engine, a greyhound bus and a Studebaker, the packaging for Lucky Strikes, food and soft drinks, to name the most prominent. And he's just as well known for his marketing skill..." (p. 8). Just as the arts have rhetoric and inquiry and the sciences have the scientific method, technology has design. And although the discipline of design draws on arts and sciences, it also has its own body of knowledge. Cross (2007) stated it this way: "Design has its own distinct' things to know, ways of knowing them, and way of finding out about them (p. 17). Design can become the *anchor,* the *common theme,* and the *driving force* in helping learners experience technology. Like art and science, design is a way of responding to a challenge. When confronted with a problem, a scientist might establish a hypothesis, conduct an experiment, gather data, assess it, and then try to respond to the problem. Someone in the arts might instead review arguments made by others faced with the same challenge, develop his or her own conclusions, posit a position, and then express it as a creative work (literary, performance, culinary, etc.). In both cases:

- The process used is generally either right or left brained but not both.
- The process is generally linear.
- There is generally significant focus on the response, the "answer" or the "creative work".
- The data or ideas that inform the response are often verifiable or can be known.

In contrast to an artist or scientist, a designer confronted with a problem might conduct an iterative series of explorations and ventures, alternatively using intellectual and intuitive modes. The explorations involve observing and assessing, and the ventures involve the brainstorming of possible responses. The two modes are repeated, with the designer increasingly refining the proposed response. The process alternates between left brained and right brained, but they are not used simultaneously.

- The process is iterative, repeated multiple times, each time coming closer to satisfying the challenge.
- The data that inform the response are often complex, interrelated,

> subtle, subjective, elusive, and often change while the design is being pursued.

Logic and intuition can often work together on a subconscious level to solve a problem. After collecting significant amounts of data about a problem, logic alone is often insufficient to integrate all the diverse considerations and come up with an elegant solution. This phenomenon is why one must sometimes “step away” from the problem to give the subconscious, intuitive side a crack at the problem. Trying to solve a complex problem with intuition alone is seldom effective, because collecting information and grouping it logically is usually a prerequisite to the effective application of intuition. The subconscious nature of intuition helps explain why expert problem solvers often find it difficult to express exactly how they came to their creative solutions.

According to Yatt (2010), design is its own discipline with its own set of mental processes and outcomes. He expressed his perspective on these issues when he wrote

> Design merits being classified as its own discipline not by virtue of the fact that it produces a different product than science or art. In fact, no particular product is a necessary outcome of the discipline of design, what distinguishes design is *the nature of its process.* The arts tend to be right brained—their bodies of knowledge are expressive and their processes are intuitive. The sciences tend to be left brained—their bodies of knowledge are empirical and their processes are logical. By contrast, design is *both right and left brained; its* bodies of knowledge that are both *expressive* and *empirical,* and its processes are both *intuitive* and *logical.* One might, in fact, reasonably define design as the discipline of comprehensive, or holistic, thinking. In fact, both artists and scientists are likely to engage in design at some point as they follow their respective disciplines. (p. 4)

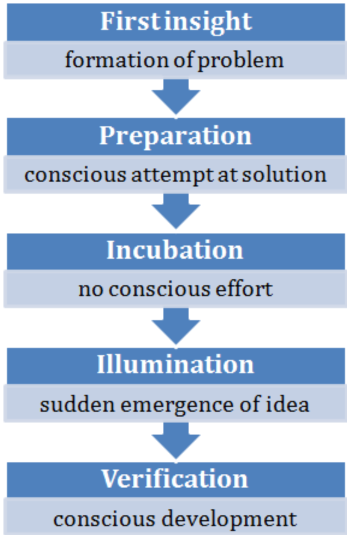
Yatt (2010) wrote in another section that

> Design is a discipline that makes it possible to respond in a creative, imaginative, and holistic way to a complex mix of seemingly unrelated concerns and issues. Although we often describe designers as people who ‘think outside the box’, one might far more accurately describe true designers… as those who harness insight to enable them to push the limits of the box. It isn’t possible to think outside the box without fully and deeply understanding the edges of the box and all it defines and contains. (p. 4)

What if average people could develop the kind of outside-the-box creativity that distinguishes architects and inventors, and use it to develop insightful responses to the challenges that arise in their own lives? Using creativity, every human being can learn to think outside the box to some degree, to begin to draw on intuition as well as intellect, their rational side and their intuition to think up creatively appropriate solutions to difficult problems. Drawing solely on the objective left hemisphere of the brain is just as limiting and ultimately ineffective as drawing solely on the subjective right hemisphere of the brain. In other words, neither the accountant nor the artist in each of us alone can do the job completely when the challenge is too complex for either hemisphere to handle it alone. Often it is the intuitive right brain that comes into play when generating a wide range of responses, even if it is the logical left brain that vets these ideas and applies to them the details that make them reality (Pink, 2006). Imagination can sometimes do its best work in the subconscious. Sometimes sleeping on a problem is the best advice, as it gives the intellect a rest, allowing the subconscious a chance to operate and play its essential role in problem solving. We often awake to insights, because creativity is encouraged when a little cognitive distance is gained (Barrett, 2001; Goleman, Kaufman, & Ray, 1992).

Kneller (1965, pp. 47-57) identified a five-stage model describing the creative process (see Figure 2 next page).

Figure 2. Kneller's Creative Process Model



Source: "The Art and Science of Creativity" by G. F. Kneller (1997).

1. First insight involves the identification and clarification of the problem or challenge.
2. *Preparation* is the research stage. As the designer gathers data he or she will often revisit the first insight stage and redefine the challenge.
3. *Incubation* occurs when the rational, left hemisphere of the brain disengages allowing the intuitive right hemisphere to process complex variables. As shown by Figure 2, this stage best occurs in the subconscious. Lawson (1997) illustrated this point in describing the work of James Watson and Francis Crick who discovered the double helix shape of DNA, "The structure of DNA as we know it today simply could not be logically deduced from the evidence available to Watson and Crick. They had to make a leap into the unknown, a demonstration of divergent thought par excellence!" (p. 156) Incubation is important in approaching design as a creative process, as opposed to solely a problem solving process.
4. *Illumination* occurs when the mind has reorganized and prioritized the information gathered in the preparation stage and a solution become apparent.

5. *Verification* includes testing, refining and developing the idea to fulfill the final stage of the creative process.

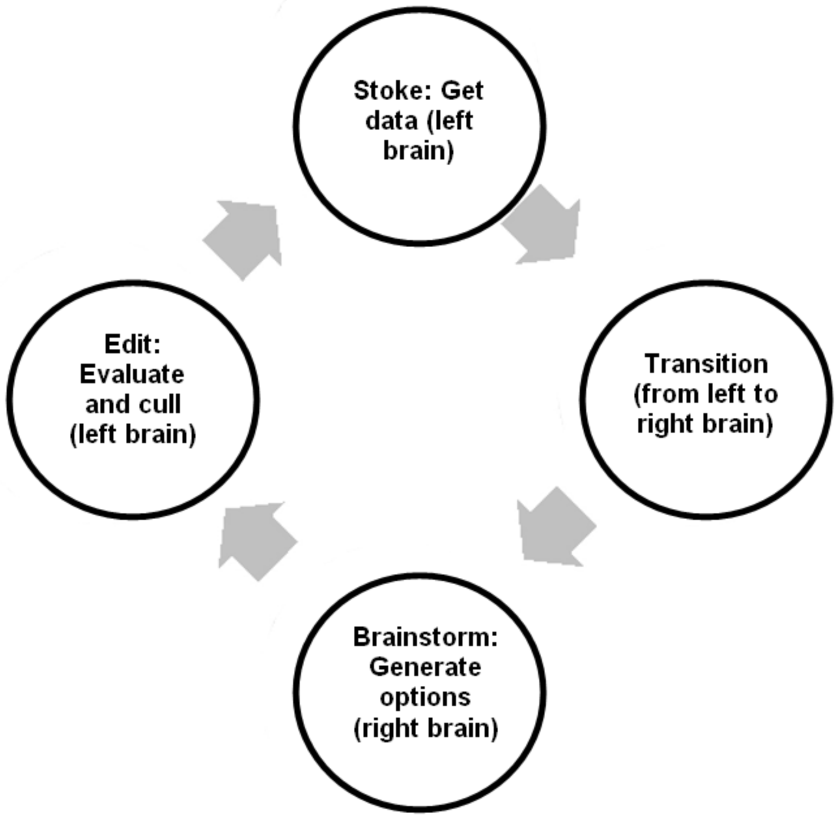
Our experiences with architectural design and design education suggest the need for modifications to Kneller's model, resulting in a more fluid approach to design. The following points are of note:

- The Kneller model started with problem definition (i.e., first insight). This beginning stage is efficient, because generating alternative responses before understanding the challenge can be a waste of time. For some, it is a necessary first step toward bringing one's creative abilities into the process of creating a response to the challenge. However, starting with problem definition may not suit the personalities of all designers. Because design is an iterative process wherein the designer cycles through the steps multiple times, where one starts may be less critical than finding and using a process that works.
- Once the problem is defined, the Kneller model goes right to preparation, a conscious attempt at solving the problem. We have observed that there is danger in trying to go too quickly to solving a problem, and would stress the importance of exploring it first before making any focused attempt to solve it. We suggest that going to incubation, where brainstorming happens, before preparation, is a more productive order for these two steps.
- Note that incubation involves a lot of effort, even if it is not conscious. Brainstorming should be exhaustive and can be exhausting.
- Illumination is not really a stage, and it generally does not happen suddenly. It happens when it happens, and like the process as a whole, it happens multiple times, at multiple levels, at multiple points along the way.

Figure 3 (next page) describes a model for design that uses both the left and right hemispheres of the brain. Instead of linear, it is circular. It repeats until the designer or design team runs out of time, interest, or energy, or whenever they decide that the solution is good enough. Its elements are

- stoking (left-hemisphere data gathering, analysis, and application)
- transitioning (from left- to right-hemisphere mode)
- brainstorming alternatives (right-hemisphere)
- editing options to cull weaker ones (left-hemisphere)
- repeat

Figure 3. A Design Process Model Utilizing both the Rational and Intuitive

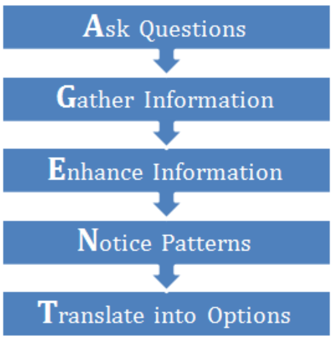


While brainstorming was already explored in the section on creativity, the other three have not been. In each iteration of the design process brainstorming eventually reaches a tentative conclusion. This completion happens when the well of creativity has divulged all it can without additional input. It is the time to sort through all of the alternatives and evaluate them. This is a time of questioning, largely of comparing the alternatives generated with the project's goals to figure out which alternatives respond most effectively and comprehensively to those goals. In the end, only those alternatives should remain that have strong potential to address the problem. It may not be clear yet which is the best, and it is very likely that all of them could use further refinement. But before doing further editing, and so long as time remains, one will likely want to get more information to use in generating yet more alternatives, more sophisticated and nuanced alternatives, from those that remain. We will now look at stoking, which is the process of gathering and assessing information, as well as transitioning.

Stoking. In the design professions the process of doing preparation for responding to a challenge is known as stoking (Yatt, 2001,2008). One effective technique for stoking involves five steps that form the acronym AGENT (see Figure 4):

1. Ask questions
2. Gather information
3. Enhance the information to make patterns
4. Notice the implications of the patterns
5. Translate the implications into design options (Yatt, 2010)

Figure 4. The "AGENT" Design Stoking Model



The two steps most unique to the design process are enhancing and noticing. The two are often simply referred to as analysis, but for design, using processes that engage the subconscious helps the analysis.

Analysis, while primarily intellectual, is not necessarily at its most effective when it is limited to poring over statistics and written data. We often recognize data patterns most effectively when they are presented in a form that registers subconsciously. But what kind of information registers subconsciously? Patterns in data that are presented as drawn (2D), modeled (3D), or animated (4D) graphic representation of words and numbers are often far more easily recognized on a "gut" level. How much faster and more accurate is a response to a graph than to a table of statistics, even though they both document the same set of data?

As an example, consider the following: An architecture student, who is asked to design an elementary school, wonders where to locate the entrance. The student gets data on the forms of transportation used by different groups of users, thinking that it would make sense to put the entrance on the side of the building at which people would be arriving.

The architecture student finds that for students, 45% walk, 20% come by car, another 25% use the bus, and the remaining 10% come by the Metro system (the subway). The architecture student gets similar data for the teachers and staff, but the findings are seen just a bunch of numbers. This situation lends itself, perhaps, to intellectual comprehension, but not so much to intuitive comprehension. So, since the architecture student wants to be able to draw conclusions easily, it is decided to arrange the data in a table, as shown in Figure 5.

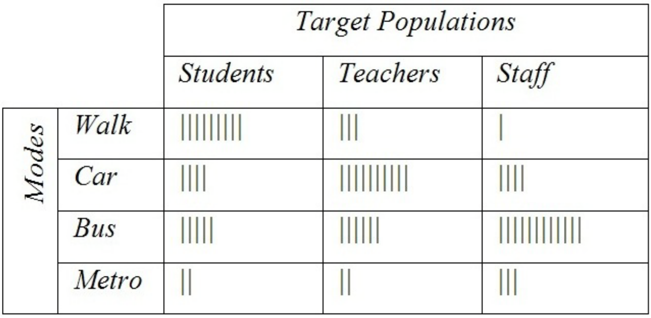
Figure 5. Table with Numbers

		Target Populations		
		Students	*Teachers*	*Staff*
Modes	*Walk*	*45%*	*10%*	*5%*
	Car	*20%*	*50%*	*20%*
	Bus	*25%*	*30%*	*60%*
	Metro	*10%*	*10%*	*15%*

Source: "Definition: Gaining Insight" by B. Yatt (2010). Used with permission.

This is an improvement, but the student thinks the findings can make it even more expressive. The table showed relationships better than the plain numbers did, but the student knows it will work better as an analysis tool if the numbers are removed. So bars are substituted whose lengths correspond to the numbers, as shown in Figure 6.

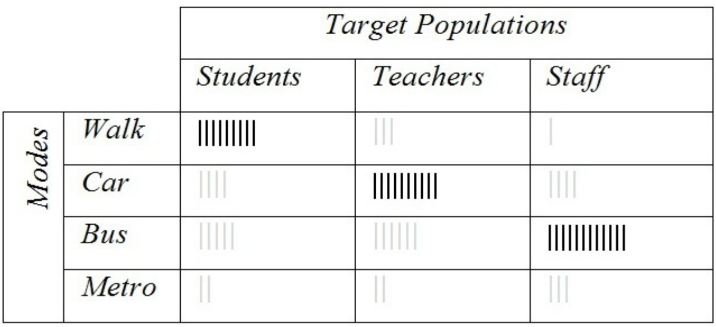
Figure 6. Table with Bars



Source: “Definition: Gaining Insight” by B. Yatt (2010). Used with permission.

With this done, the architecture student is able to see patterns in the graphic arrangements of the data rather than have to make conceptual patterns with the numbers, a process that engages the intuition better. This helps the student see that each population used one form of transportation far more than the other two, but it was a different form for each group, as shown in Figure 7. Yes, this same information was there in the raw data, and in the table with the numbers, but it did not stand out as it does with the bars. As they say, a picture is worth a thousand words. The bars helped give a “gut” sense of what the numbers represented.

Figure 7. Recognizing Patterns



Source: “Definition: Gaining Insight” by B. Yatt (2010). Used with permission.

This example shows how information can be digested into the subconscious. After using such techniques, a designer can return to brainstorming to see what further ideas might present themselves. This repeated cycle of problem stoking (insight), brainstorming (incubation), evaluating and editing (preparation), leading to (illumination), moving slowly but iteratively toward a strong response, is the essence of the design process.

Transitioning. Once information sufficient to answer the initial questions has been gathered, one can start to get creative. But before unleashing the right brain, a transition period is important, especially before proficiency in the design process is achieved, because thinking logically and thinking intuitively are so different. One cannot just jump from one mode to the other, at least not without a lot of practice. And, the two modes cannot be done at the same time since they inhibit each other. Brainstorming is limited and censored by logic. Logic's careful order and sequence is interrupted and thrown off by brainstorming. Thus, good design work requires "serial schizophrenia", where each half of the brain is put to work independently of, and without being distracted or confused by the other. Time and distraction are critical elements in winding down and shutting off the left-hemisphere in anticipation of powering up the right-hemisphere.

During this transition period, it is important to get distracted by something else, anything else, doing nothing related to the challenge. This time allows the brain to *switch over* from left hemisphere to right, from an ability to work intellectually to an ability to work intuitively. And just as critically, the transition time allows the gathered information to percolate down into the subconscious, where the right hemisphere can get access to it when brainstorming. This transition time can take two minutes or two weeks, and decreases with practice.

When the transition from logic to brainstorming mindset is finished, one can productively engage the right hemisphere. This repeated cycle of right and left hemispheric thinking, with transitions as needed and stoked with additional insights as necessary, is the essence of the design process.

Art and Craft. Historically, human knowledge and skills have become increasingly specialized. Burke (1978) argued that the start of that specialization began with the start of agriculture. The process would accelerate exponentially with the industrial revolutions of the 18^{th}, 19^{th}, and 20^{th} centuries. However, art, craft, technology, and engineering, regardless of how specialized their knowledge and skills may have become, still share the common threads of creativity and the design process.

The terms *art* and *craft* carry many different connotations in many different contexts, especially as they relate to design and technology education. They also carry connotations in everyday use (e.g., artist versus craftsman, fine art versus applied art, patron of art versus customer for craft), but the current exploration will be more limited, focusing on the design context, where art and craft differ in their use of insight and the extent to which they benefit from the intuition. It is difficult to discuss one without the other, so they are treated here as a duality.

In spite of having an immediate history labeled industrial arts, technology education and its predecessor curriculums has generally focused more on craft than art. Yet it is easily argued that a craftsman can eventually become an artist. The masterpieces on display at the *Museé des Campagnonages* in Tours, France[1], are a perfect illustration of this idea. *Campagnonages* are guilds, and this museum is filled with demonstration projects in roofing, basket weaving, blacksmithing, saddle making, baking, and more. Some of these displays are hundreds of years old, made by journeymen proving their worth as master tradesmen (hence the term "masterpieces"). These works reflect the joy and imagination, as well as the diligence and mastery, of people steeped in their techniques and comfortable with experimentation, to the point that their craft has become second nature to them and they can become inventive beyond anything they learned from their masters.

The craftsman is trained to apply particular techniques to particular situations. For example, 1½ cups of water mixed with 4 cups of flour can make dough suitable for bread. When that combination is produced over and over again, eventually the baker starts noticing subtle differences. If the dough is made with slightly more or less water relative to flour, the dough behaves slightly differently, suggesting differences in the end product (e.g., bread, pizza crust, pasta) that could result. After learning, by experience or training, hundreds of subtle differences caused by water-flour ratio, and more hundreds of subtle differences caused by flours ground to different degrees of granularity, and even more hundreds caused by differences in the region where the flour's grain was grown, sooner or later the possibilities become overwhelming. The master baker, therefore, stops depending solely on his left hemisphere, his storehouse of facts, when he bakes and starts also involving his right hemisphere, his intuition. It is again this harnessing of both halves of the brain, this combination of knowing facts with a less tangible attitude of *je ne sais quois* (literally *I do not know*), this mixing of techniques with hunches, of attention to detail with grand gestures, that is the essential difference between a craftsman and an artist.

It can easily be argued that one cannot set out to make art. Instead, art evolves naturally when mastery of individual technique has become sufficiently complete at the same time that a highly complex set of challenges is presenting itself for resolution. In this context, a craft is the product of skill; whereas, an art is the product of vision. A craft makes an undertaking do-able but an art makes it worth doing. A craft responds to a problem by making it functional, but an art responds by making it memorable. Without craft, art cannot be realized. Without art, craft fails to inspire reflection. This discussion all starts to smack of poetry, which leads to the next aspect of creativity: story.

Story. Pink (2006) believes that those people who are able to effectively apply the right hemispheres of their brains will rule in the new "conceptual age." One of the six aptitudes that Pink advocated for successful participation in this conceptual age is story. "Stories are easy to remember—because in many ways, stories are how we remember (p. 99)." Turner (as cited in Pink, 2006) wrote "Narrative imagining—story—is the fundamental instrument of thought. Rational capacities depend on it. It is our chief means of looking into the future, of predicting, of planning, and of explaining…Most of our experiences, our knowledge, our thinking is organized as stories" (p.99). To Pink, "story is just as integral to the human experience as design" (p. 99).

Norman (Norman & Dunaeff, 1994) explained that story is both high-concept and high-touch:

> Stories have the felicitous capacity of capturing exactly those elements that formal decision making methods leave out. Logic tries to generalize, to strip the decision making from the specific context, to remove it from subjective emotions. Stories capture the context, capture the emotions.... Stories are important cognitive events, for they encapsulate, into one compact package, information, knowledge, context, and emotion. (p. 146)

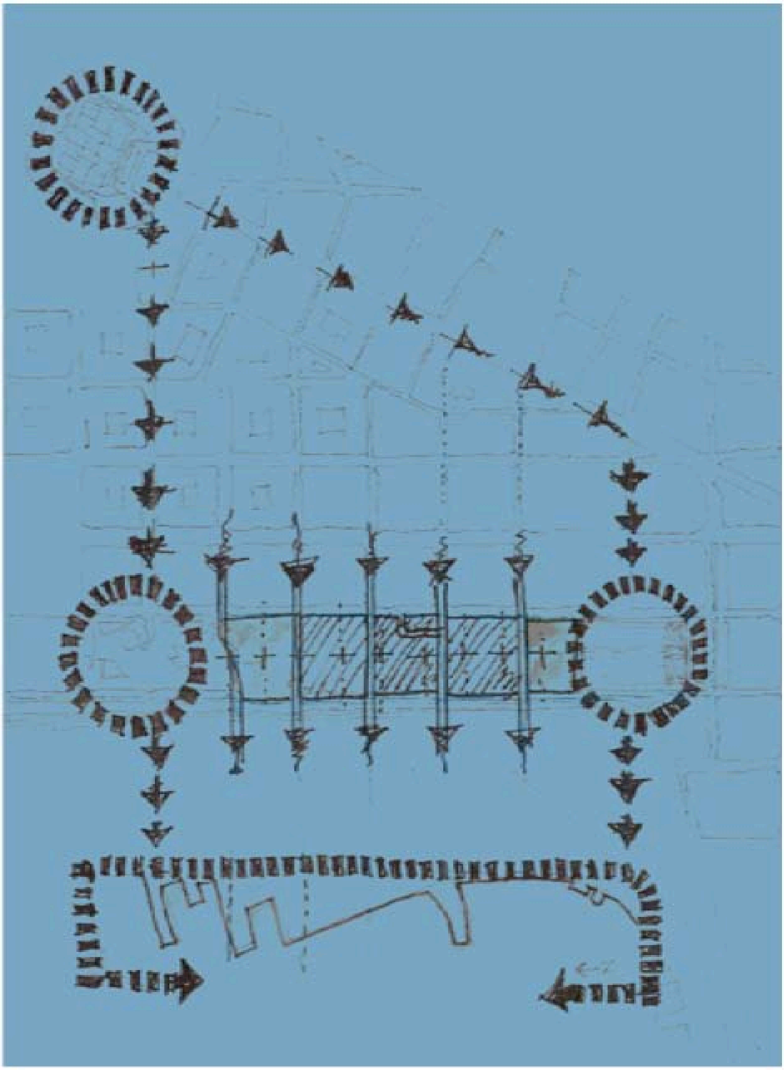
Story is perhaps the most important element in the design process. Story could also be thought of as plot, narrative, or path. It is the holistic vision and the handle by which the mind can retain a complicated set of data points. It is the key element in bringing the right half of the brain, where intuition resides, to bear on a challenge. Without story, only the left half of the brain, where logic resides, tends to be harnessed. Without story, the myriad aspects of the challenge and the multiple alternatives that a designer brainstorms in response, are just so many equally compelling options. And too many aspects and alternatives tend to overwhelm “standard” thought processes.

Story makes ideas memorable and makes hopelessly complex amalgamations of elements able to be held by the human mind. It is what allows the human mind to see patterns, to simplify, and thus to wrap itself around what otherwise might simply be unrelated sets of terms, facts, images, or ideas. Story is a key element in bridging intellect and intuition so that they can work together in responding to challenges.

The sketch shown in Figure 8 (next page), from the design work of an architecture student, overlays a diagram on a map of a downtown area in an attempt to distill a story about movement. The three dotted circles indicate places that serve as circulation nodes, where people slow down and reorient themselves before proceeding. The dotted rectangle at the bottom indicates the presence of a waterfront area that is a common goal, a viewpoint if not an actual destination, an “end of the story”, for those in the area. The arrows attempt to show the way people might move through or past the site, the rectangle in the middle of the image between two of the circles. This diagram, and the act of drawing it, starts the mind thinking, starts to help the designer get an intuitive feel of the forces acting on the site, starts to tell the story.

Story is what led ancient mariners to see animals in rather random groupings of stars and even to name them as constellations. How much easier is it to understand the idea of navigating toward the “end of the little dipper’s handle” than to aim for what would be the 62nd star above the horizon if it’s July 18th at 9:27 in the evening? Story reduces a complex set of phenomena or elements or actions into basic ideas. And as challenges involve increasing numbers of elements, multiple sets of stories can be strung together into larger mental images that can be used to harness this complexity. Stories also tend to lead to other stories, suggesting further possible responses and more out-of-the-box thinking.

Figure 8. Sketching Over a Map as a Way to Think Through Possible Stories About Movement



Einstein came up with the theory of relativity after imagining himself “riding on a beam of light,” clearly an intuitive insight, even though he ultimately expressed his theory using logic, as the mathematical formula $E=MC^2$. Newton imagined gravity as an apple falling from a tree. Contemporary physicists talk about the even more complex “string theory”. Each of these happenings is an attempt to capture the complexity of a challenge or its solution as a simple story. Stories provide an anchor, a reference point, for managing all of the hundreds or thousands of facts and thoughts that comprise the entire scope of a challenge. Ultimately, the use of story tames problem-solving, thereby making the design process possible.

Story is the element that enables holistic understandings of complicated problems. With story, the design process can begin to work its magic, alternatively moving from the right hemisphere of the brain to left and back again, in one moment letting imagination manipulate elements while they are easily manipulated—compressed and expressed as stories—and then in another moment letting logic focus on, expand, and “drill down” into one or two elements within the overall story without the distraction posed by the other elements of the challenge, to ultimately manage to succeed in responding to a challenge’s otherwise overwhelming complexity.

THE ROLE OF CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

With these understandings of technology, engineering, creativity, design, art, craft, and story, one can start to look at their role in technology education. A challenge central to the mission of technology education is to prepare students to make critical choices about complex challenges created by technologies of ever increasing power. As this power exerts more and more leverage over our world; the stakes grow higher. These stakes require a decision making process not limited to either hemisphere of the brain.

The difference between responding to challenges driven primarily or exclusively by logic, and solving problems grounded in logic but fueled by creativity, helps explain the difference in the complexity of the situations each can manage and the elegance with which each can do it.[2] Creativity and design are critical to being holistic in such a way that other related problems are eliminated in the process.

When bringing creativity and design into the classroom, there is the question of whether student work can be evaluated in an objective way. As mentioned earlier, creativity can be abstract or applied. Abstract creativity generally draws heavily on self-expression. It is usually primarily artistic in nature, making a statement and responding to emotional matters. Its "designs" can be very subjective, a matter of personal perspective or "taste". Applied creativity, on the other hand, is concerned with responding to problems that are more often physical or logistical. Its solutions may well reflect the designer's intuition and artistic flair but are intended to strike a balance between form and function, between responding to emotional and practical problems. This kind of creativity results in work that, to a large degree, can be judged against criteria that is external to the designer. Thus, it is possible to conclude that a student design is strong even when the instructor finds its aesthetic not to his or her liking.

A critical role of creativity and design in technology education is to help students develop more holistic, more flexible, more adaptive ways of thinking and responding to the increasingly complex problems encountered in contemporary situations, by adding the power of their brain's right hemisphere to what they have already developed with their left hemisphere. The proper role of creativity and design in technology education is unlikely to manifest if design is taught as if it emerges from the combined perspectives of scientist and artist. That is because design (process) is not a hybrid of other processes, and effective designs (product) do not result from following any number of non-design processes, but rather result from following the unique process that is design. The fundamental definition of the design process, as creative problem solving, evokes an approach that demands both intuition and reason, not as separate approaches used in different disciplines but as a single holistic and multidisciplinary approach.

One measure of the status of creativity and design in technology education is the amount of discussion of these topics within the professional literature. Warner (2010) searched *The Technology Teacher* (TTT) and the *Journal of Technology Education* (JTE) in an attempt to determine the extent to which creativity and design have been recognized in technology education. He found a total of 350 TTT articles written between 1998 and 2008. Only three of their titles contained the words "creativity" or "creative." For the same ten year period, Warner found only three more articles containing those words in the JTE. Considering the importance of design in teaching technology the relative absence of scholarly work centering on creativity is of concern. At the very least, an exploration of the role of creativity in the design process is indicated. This is especially critical since technology educators tend to focus heavily if not exclusively on engineering. Of course, an emphasis on math and science does not and should not preclude an emphasis on creativity but rather almost demands it, despite what history suggests. Perhaps the best way to look at teaching design, the process of creative problem solving, is as a balancing act. The trick is to give students knowledge, skill, and experience without "mechanizing his or her thought process to the point of preventing the emergence of original ideas" (Lawson, 1997, p. 161).

APPLYING CREATIVITY AND DESIGN TO TECHNOLOGY AND ENGINEERING EDUCATION

According to Lawson (1997), "both convergent and divergent thought are needed by both the scientist and artist, it is probably the designer who needs the two skills in most equal proportions. (p. 156)

Too often, we fail to balance the rational and the intuitive in design instruction. As we have seen, responding to complex problems requires more than a singular, literally unilateral, approach based solely upon either right- or left-brained thinking.

The first step in applying right-brained thinking to technology education is getting students to feel comfortable with being creative and imaginative.[3] We teach students, overtly and in subtle ways, that intuition is not to be taken seriously or even trusted, and that only logic is associated with maturity, intelligence, effectiveness, and reward. We essentially leave creativity behind with crayons and kindergarten except for those who tend to be marginalized or who self- marginalize as "creative types". Creativity is often seen as superfluous, something for which the traditional business world has little time or patience. However, schools and society need to change these messages for the sake of addressing the complex issues we face, because for such challenges, the most efficient way to an optimal solution requires the seemingly inefficient design process, requires taking one's eyes off of the challenge long enough to brainstorm, to imagine, the best response.[4]

It is beyond the scope of this text to propose how creativity might be realized for our culture at large, but there might be ways that technology education programs could start, perhaps by teaching the idea of design as a process, one that alternately uses left- and right-hemisphere based approaches to problem solving to arrive at a response that neither alone could achieve. Since technology programs are generally more focused on teaching logical approaches than intuitive approaches to problem solving, we need to think about how, exactly, we might change that. Let us look at how stoking and brainstorming, and the design process as a whole, might actually be used in the classroom.

Stoking in the Classroom. As noted, the design approach starts like any logic process, generally but not always starting with the left - hemisphere gathering data that will inform the upcoming intuitive venture. Students can use any of a number of approaches to gather data including reading, interviewing, polling, measuring, experimenting, and testing, until they get information of sufficient quality and quantity to inform a response. The AGENT process can be a very effective way to prepare raw information so that it can inform brainstorming. Along with AGENT, it will likely be important to push students to use intuition in their analysis work, perhaps by asking them to translate the data they find into graphic form, to help them understand it on a gut level, or by having them play with the data until it works its way into their subconscious.

The critical element with information gathering is to take it far enough. Information is not gathered just for the sake of having information. Students too often think they are finished when they have a list of facts or a graphic expression of facts (e.g., a map). But until implications for design are extracted, these facts are of almost no use. Students must confront the "so what" question: "So what difference does it make to have found the information you found - how does it change your design options?" Only with the answers to those questions can one start to brainstorm.

Brainstorming in the Classroom. Remember that brainstorming has a lot to do with play. Its goal is to increase the number of alternative solutions, to create, where the goal of logic is to reduce them, to edit. Brainstorming is consciously unrestrained but subconsciously guided. This principle means that when brainstorming, students must consciously try to avoid thinking about why any particular solution might not work or might be inappropriate. During brainstorming, students come up with ideas that they did not know they had; thus, they are "inspired".

Students often need to be pushed with regard to these attitudes. Going against the status quo can be difficult and in all likelihood young people will be using these attitudes in an educational or business system that discourages them. It takes time, perseverance, and patience on the part of the students. Instructors need to encourage brainstorming. Once creative work is temporarily done, once brainstorming has reached the limit of its store of creativity, once inspiration dries up, the entire process is sent back, for another spin of the cycle, to the more familiar left- hemisphere realm of logic.

For technology educators wanting their students to use both sides of their brains, starting to brainstorm might involve encouraging students to experiment, to simply explore a problem before solving it, to deeply understand a challenge before responding to it, to play, and to do so by *doing* rather than by talking or "thinking". Remember that a critical rest period, distraction time, makes it possible for students to successfully turn off their intuitions and engage their intellects whenever necessary.

Ultimately, the point of teaching students to brainstorm is to get them to play with the realm of possible responses rather than looking only for the best response, to expand their thinking through brainstorming before contacting it through logic, through editing out the weaker alternatives. But weak alternatives cannot be edited out unless there are many to choose from, and generating many alternatives is the role of brainstorming.

Designing in the Classroom. Ultimately, there is no need to wait for inspiration. With practice, creativity can be made to happen by properly applying the design process[5]. A holistic approach to design, one that teaches the learner to use both hemispheres of the brain, requires some resources, particular in terms of time and patience. It requires an intentional and ongoing effort to balance classroom experiences that engage both the left and right hemispheres. These types of experiences will lead students to discover and expand their intuitive and their rational capabilities.

In the end, it seems clear that the importance of the potential gains in technology and engineering education makes the effort not only worth pursuing but necessary for excellence.

REFLECTIVE QUESTIONS

1. The authors of this chapter suggest that design is a process that draws on both the left side and the right side of the brain. What are some practical ideas you might use to push your students to use creativity in the design process?
2. Barry Yatt is a practicing architect and design educator. In what ways does the discussion in this chapter challenge the leaders of and teachers in technology education as the profession moves toward engineering?
3. How could you restructure projects you currently use in class so as to ask students to stoke and to brainstorm – to stoke their subconscious in preparation for brainstorming, and then to brainstorm some preliminary solution ideas?
4. Do you agree with the authors that *story* is a critical element in the design process? Why or why not?
5. What opportunities or problems do you think the challenge/ responding approach proposed in this chapter might have for you or your students?

FOOTNOTES

[1]Additional information on Museé des Campagnonages in Tours, France can be accessed at http://www.compagnons.org

[2]Creative Thinking Skills for Life and Education by Craig Rusbult http://www.asa3.org/ASA/education/think/creative.htm

[3]Creativity and Creative Thinking (includes lesson plans) by Mary Bellis: http://inventors.about.com/od/lessonplans/a/creativity.htm

[4]Ken Robinson says schools kill creativity http://www.ted.com/talks/lang/eng/ken_robinson_says_schools_kill_creativity.html

[5]Architecture+Design Education Network and Association of Architecture Organizations http://www.adenweb.org/

REFERENCES

Barrett, D. (2001). *The committee of sleep: How artists, scientists, and atheletes use dreams for creative problem-solving — and how you can too*. New York: Crown.

Boden, M. A. (1991). *The creative mind: Myths & mechanisms*. New York: Basic Books.

Breckon, A. (1988). *Design and realisation.* London: Collins Educational.

Breitenberg, M. (2003, May 15–16). The Radical Nature of Design. *ICSID Design Congress 2003*. Retrieved from http://www.acido.info/ICSID_news/ICSIDnews3-4=2003.pdf

Brown, S. (2009). *Play: How it shapes the brain, opens the imagination, and invigorates the soul*. New York: Avery.

Brown, T. (2009). *Change by design: How design thinking transforms organizations and inspires innovation*. New York: HarperCollins.

Burke, J. (1978). *Connections*. Boston: Little, Brown and Company.

Cross, N. (2007). *Designerly Ways of Knowing*. Basel: Birkhauser Vertag AG.

Csikszentmihalyi, M. (1996). *Creativity: Flow and tlhe Psychology of Discovery and Invention.* New York: HaperCollins.

Design. (2009) In *American Heritage Dictionary of the English Language* online edition. Retrieved from http://education.yahoo.com/reference/dictionary/entry/design

DeVore, P. W. (1980). *Technology: An introduction*. Worcester, MA: Davis.

Gardner, H. (1993). *Creating Minds: An anatomy of creativity seen through the lives of Freud, Einstein, Picasso, Stravinsky, Eliot, Graham, and Gandhi*. New York: Basic Books.

Goleman, D., Kaufman, P., & Ray, M. (1992). *The creative spirit*. New York: Penguin.

Harrisberger, L. (1982). *Engineersmanship…The doing of engineering design* (2nd ed). Boston: PWS-Kent.

Hutchinson, J., & Karsnitz, J. R. (1994). *Design and problem solving in technology*. Albany, NY: Delmar Publishers.

International Technology Education Association. (2000). *Standards for Technological Literacy: Content for the study of technology.* Reston, VA: International Technology Education Association.

Kelly, T. (2001). *The art of innovation*. New York: Currency Books.
Kneller, G. F. (1997). The Art and Science of Creativity. In B. Lawson, *How Designers Think: the design process demystified* (pp. 151-153). Burlington, MA: Architecual Press.
Lawson, B. (1997). *How Designers Think: the design proces demystified.* Burlington, MA: Architectual Press.
Mayer, R. E. (1999). Fifty Years of Creativity Research. In R. J. Sternberg, *Handbook of Creativity* (pp. 449-450). New York: Cambridge University Press.
Norman, D. (2006). Things That Make Us Smart. In D. H. Pink, *A Whole New Mind: Why right-brainers will rule the future* (p. 103). New York: Riverhead Books.
Osborn, A. F. (1953). *Applied imagination*. New York: Charles Scribner's Sons.
Pearson, G. & Young, A. T. (Eds.). (2002). *Technically speaking: Why all Americans need to know more about technology*. Washington, D.C.: National Academy Press.
Petroski, H. (1992). *The evolution of useful things: How everyday artifacts — from forks and pins to paper clips and zippers — came to be as they are*. New York: Alfred A. Knopf.
Pink, D. H. (2006). *A Whole New Mind: Why right-braineers will rule the future.* New York: Riverhead Books.
Pinker, S. (1997). *How the mind works*. New York: W. W. Norton.
Sternbeerg, R. J. (1988). *The Nature of Creativity.* Cambridge: Press Syndicate of the University of Cambridge.
Tardif, T. Z. & Sternberg, R. J. (1988). What do we know about creativity. In R. J. Sternberg (Ed.). *The nature of creativity: Contemporary psychological perspectives* (pp. 429-440). New York: Cambridge University Press.
Taylor, D. W., Berry, P. C., & Block, C. H. (1958). Does group participation when using brainstorming facilitate or inhibit creative thinking. *Administrative Science Quarterly, 3*(1), 23-47.
Treffinger, D. J., Young, G. C., Selby, E. C., Shepardson, C., & Center for Creative Learning Sarasota, Florida (2002, December). *Assessing creativity: A guide for educators*. The National Research Center on the Gifted and Talented. Retrieved from http://www.creativelearning.com/PDF/AssessCreatReport.pdf

Vanderdray, L. (2006). *Healthy bodies, healthy buildings: A farmer's market and cooking school for Washington, DC* (Unpublished master's thesis). School of Architecture and Planning, The Catholic University of America, Wsashington, D.C.

Vehar, J. (2010, July 19). *Don't forget, brainstorming works!*. Creative Education Foundation. Retrieved from http://www.creativeeducationfoundation.org/?p=916

von Oech, R. (1998). *A whack on the side of the head: How you can be more creative*. New York: MJF Books.

Warner, S. A. (in press). Creativity and design in technology education. In P. Reed & J. LaPorte (Eds.), *The Status of Research in Technolgoy Teacher Education.* Reston, VA: Council on Technoloy Teacher Education.

Yatt, B. (2001). Design process for architecture students. Unpublished manuscript, School of Architecture, The Catholic University of America, Washington, D.C.

Yatt, B. (2008). *Expansion: Seeking options*. Retrieved from http://archprac.cua.edu/15-2008/Expansion33FirstChapts.pdf

Yatt, B. (2010). *Definition: Gaining insight*. Available through http://www.lulu.com/product/paperback/definition-gaining-insight/12444379-detailsSection

The Many Forms of Creative Expression

Chapter 3

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Inconsistency exists between the type of capabilities students are required to demonstrate in school and what is expected of them once they leave. With educational standards being adopted and refined for all subjects in many states of the United States, and the increased usage of standardized test results employed to benchmark individual school success, the tendency for teachers to *teach to the test* and students to subsequently learn about the world around them in a rote and myopic fashion can be expected (Ediger, 2000). Ironically, business and engineering communities emphasize the importance of "outside the box" thinking and the need for creative solutions as a result of competitive market pressures that characterize today's global economy (Mahboub, Portillo, Liu, & Chandraratna, 2004). As a result, questions arises amid these competing paradigms: How and where in the curriculum are students allowed to exercise their innate creative urges, and, how is creativity fostered in students? For technology education, with its current curricular efforts focused on the infusion of engineering concepts that inherently demand creative thinking, providing opportunities that nurture creativity is of particular interest.

Other factors outside education also provide motivation for technology educators to discover the educational power of their subject area. The New Commission on the Skills of the American Workforce (National Center on Education and the Economy, 2007) recommended that the education and training systems of the United States be revitalized to prepare a globally competitive workforce for the 21st century. Teaching children the needed employability skills requires different teaching methods, learning materials, school structures, and assessment techniques. Simply put, the roles of teachers and students are changing. Many of these changes are focusing attention on the development of higher level thinking skills and the kinds of pedagogical methods used by creative educators: active learning; personal involvement in learning; in-depth experience with real life, complex problems; use of technology to aid thinking; information management; and problem solving (Houtz and Krug, 1995). Technology education, using the contemporary engineering infused curriculum, can consistently provide learning experiences for students that encourage creative thinking. Therefore, with problem solving, design, and critical thinking at the core of technology education, it is easy to conclude that the role creative thinking plays in each of these domains is crucial. Indeed, the *Standards for Technological Literacy* (ITEA, 2000) specifically recognized the importance of creativity in technology education: "Creativity, in addition to the ability to think outside the box and imagine new possibilities, is central to the process of invention and innovation. All technological products and systems first existed in the human imagination" (p. 106).

Cognitive research (Gardner, 1983; Gardner, 1993; Wallace & Gruber, 1989) has suggested multiple avenues of creative expression. Within this chapter, the different influences students, teachers, pedagogy, and the classroom environment can have on creativity are examined. The chapter culminates with instructional strategies and best practices that can be implemented by the technology educator to facilitate creativity.

INFLUENCES ON CREATIVITY

Industry in the United States has moved away from the production of goods and services and now concentrates instead on the production of ideas. Matheson (2006) pointed out that the "creative" industries have become the subject of an increasing amount of research. It has been argued that those professions that covet creativity are driving more than just economic growth. By placing creative industries at the center of civic and commercial life, they also facilitate social and cultural development (Matheson, 2006; Gans, 1999; Kunzman, 1995; Volkerling, 2000). Florida (2002) described how these industries are leading the way to a new economy that has at its core social, cultural, and environmental issues. The creative industries of this new economy have a whole new set of complex pressures. Leading this wave of change are those industries involved with the increasingly sophisticated and complex world of information and communication technologies. These industries are requiring the engineering curriculum that has been traditionally dominated by physics, mathematics, and other basic sciences, to embrace creative problem solving (Pate-Cornell, 2001). Oddly enough, one of the common requirements of post-secondary engineering programs is that students should have strong analytical and deductive skills borne of competence in mathematics and physics (T. M. Lewis, 2004). This type of training tends to direct these students to think in a convergent rather than a divergent manner. However, it is the divergent thinkers who are believed to have a natural instinct for creativity (Dyson, 1997).

Technology education, with its emphasis on creativity in design and engineering, provides powerful and unique learning opportunities. Welch and Lim (2000) contended while other subjects in the curriculum offer a problem solving approach that assumes there is only one way to find a single solution, technology education presents tasks that have many possible ways to finding different solutions. This opportunity to think divergently also provides students with opportunities to apply knowledge to generate and construct meaning. In essence, "it fosters the kind of cognition that combines declarative knowledge, the *what*, with procedural knowledge, the *how*" (p. 34).

As one might suspect, a number of nature versus nurture types of variables have been found to have their influence on creative thinking. For instance, creative attributes, or rather an individual's personality traits, have been defined as the abilities a person may inherently possess. Over half a century ago, Guilford (1950) identified certain abilities or personality traits that may be involved in creativity: sensitivity to problems, a capacity to produce many ideas (fluency), an ability to change one's mental set (flexibility), an ability to reorganize, an ability to deal with complexity, and the ability to evaluate. Guilford's ideas not only provided insight relative to issues concerning creative behavior and thinking, they helped to form an effective theory base for future creativity research (Lubart, 2000-2001).

Amabile (1983) focused on social and environmental factors that might influence creativity and identified most of them as being present in the classroom. She categorized environmental factors into areas that included peer influence, teacher characteristics and behavior, and the physical classroom environment. Grouping students in heterogeneous groups, having a teacher that is intrinsically motivated and believes in student autonomy and self-directed work, and being in a cue-rich and therefore cognitively stimulating classroom were all examples of environmental factors influencing student creativity. These factors create the classroom climate (Hunter, Bedell, & Mumford, 2007). At the individual level, the *psychological climate* (PC) represents a cognitive interpretation of a situation (James, James, & Ashe, 1990). PC theory suggests that individuals respond to cognitive representations of environments rather than to the actual environments (James & Sells, 1981). In essence, the climate of a classroom is a more global view of environmental influences on creativity.

Most of the classroom research has focused on the distinction between "open" and traditional climates (Amabile, 1983). *Openness* is most often considered a style of teaching that involves flexibility of space, student selected activities, richness of learning materials, combining of curriculum areas, and more individual or small-group rather than large-group instruction (Horwitz, 1979). In contrast, traditional classrooms consist of examinations, grading, an authoritative teacher, large group instruction, and a carefully prepared curriculum that is carried out with little variation (Ramey & Piper, 1974). As might be anticipated, most evidence regarding creativity favors open classrooms (Amabile, 1983).

AVENUES FOR CREATIVITY

Technology education is unique in offering novel and rich opportunities for students to leverage their innate strengths and cater to their learning styles in pursuing creative endeavors. Through the use of tools and materials, students can be continually active in their learning of concepts within technology education. Ted Lewis (2007) declared that mathematics and science curricula alone might not be able to produce the kind of authentic representations that characterize and necessitate ill-defined and creative work. A central theme in the nature and philosophy of technology education is that innovative ideas and products are brought to life to solve technological problems. This ethos of constructing a solution through creativity is thought to be central to technology education (ITEA, 2000). In fact, a student who is involved in problem solving in technology education is assumed to be engaged in creative thinking (Besemer & Treffinger, 1981; Jane & Robbins, 2004). It is not a leap of faith then to assert that technology education curriculums have the potential to offer needed opportunities for students to not only learn in different ways, but also to allow them to discover talents and abilities that may not be tapped in other courses.

The multifaceted ways in which learning opportunities are available and students are able to interact with the curriculum, teacher, content, and their peers within technology education have a solid grounding in the ideas and findings of educational researchers and theorists. Howard Gardner's theory of multiple intelligences was developed in part because of a concern regarding education's narrow view of what was considered as intelligence. Specific to creative work, Gardner (1993) believed there is tension between creativity and expertise to the extent that an individual could perhaps be an expert without being creative. He was also alarmed by the heavy emphasis on the constricted use of items concerned with measuring linguistic and logical abilities of students on various tests employed to measure achievement, aptitude, and intelligence (Gardner & Hatch, 1989). Gardner (1993) speculated that children possess various strengths and weaknesses, or intelligences, which ranged from linguistic to musical to existential. He advocated that equal attention should be given to those with gifts of each type of intelligence.

Drawing on Gardner's work, Daniel Goleman offered that social (Goleman, 1995), emotional (Goleman, 2006), and ecological (Goleman, 2009) specialized intelligences are also possible. In essence, a person possessing social and emotional intelligences possesses a keen ability to consider other's perspectives, be empathetic, and show concern. Ecological intelligence builds on this work and suggests that the capacity of today's communication technology to deliver product information on demand allows consumers to be privy to the environmental, health, and social impacts of their purchases. The connection to contemporary technology education is striking.

The type of creative thinking that technology education is capable of, if not obligated to cultivate, must appeal not only to the students' innate strengths but also must pay attention to the different ways they learn. Learning styles have been described as cognitive, affective, and psychological behaviors that can serve to gauge how students perceive, interact with, and respond to their environment (Keefe, 1979). Some students appear to be more comfortable with theories and abstractions, others with facts and direct observations; some are responsive to active learning, others to pondering and introspection; and some prefer visual presentations from instructors, while others would rather have a verbal explanation (Felder & Soloman, 2004; Kolb, 1981).

Considering these ideas, it seems logical that technology education teachers have substantial power to transform their classrooms and present lessons to engage students in a wide variety of ways that address different interests, abilities, intelligences, and learning styles (ITEA, 2007). In summation, the potential avenues for students *and teachers* to be creative in such a setting as a technology education class are rich indeed.

INSTRUCTIONAL STRATEGIES

Psychologists, philosophers, and instructional designers (Bruner, 1986; Dewey, 1938; Gardner, 1983; Piaget, 1963; Tomlinson, 1999; Vygotsky, 1962) have criticized traditional teacher-directed strategies, such as lectures and demonstrations, as being ineffective and incongruent with student centered teaching and learning theories. As a result, teachers and educational researchers alike have developed ideas and practices that are showing promise in providing students with fresh and elegant ways to demonstrate creativity in learning and work to capitalize on technology education's potential.

The technique of presenting students with complex, open ended design problems has been introduced in a number of different ways and to different degrees. These types of problems are designed to represent "real" scenarios or issues and have many possible solutions (T. M. Lewis, 2004). One approach to this style of instruction, termed Problem Based Learning (PBL), is multidisciplinary and regarded as "an orientation towards learning that is flexible and open and draws upon the varied skills and resources of faculty and students" (Feletti, 1993, p. 146). Technology education curricula worldwide have begun to center on the topics of problem solving, design, and construction methods (Rasinen, 2003). Roth (1996) applied PBL to enable students to construct engineering knowledge to understand the process of designing Engineering for Children: Structures (EFCS). However, Roth carefully pointed out that these activities, whose core goal is to have students construct bridges as part of an ongoing engineering competition for creating a link between two sections of a city, are not designed specifically to "transmit legitimated and canonical engineering knowledge" (p. 130). Rather, like the motivation for posing open ended problems generally, these activities provide students with opportunities to explore issues critical to designing, learn to manage the complexity of open ended design challenges, and gain knowledge of how to work with the group dynamics inherent in ill-structured design situations.

In light of the dynamic nature of industry and the marketplace, this approach makes sense. Today's professional designers (e.g., engineers, architects, industrial, and graphic) are confronted with an ever shrinking and complex world. Because of the growth of global networks and their influence on creating an international marketplace, work has less to do with making goods and is concerned more with control of automation and information (Ihsen, Isenhardt, & De Sánchez, 1998). The need for structures to withstand harsher environments, be built to greater heights, have greater controllability, and be of greater economy and safety signals the demand for creativity in engineering practices (Teng, Song, & Yuan, 2004). Specifically, Tornkvist (1998) found two common questions arose when examining creativity in the context of engineering:

1. What are the driving forces behind creativity?
2. What intentions do people have for creative work?

The answers differed with respect to the intentions for creativity:

- A person is intrinsically motivated to be creative. The fun of the process of creating is to be enjoyed in and of itself.
- A person must be creative for a purpose. Usefulness of a product is a key indicator of its creative value.
- Creativity is a factor in being competitive and subsequently successful in the marketplace.
- Fame can be a motivator for creative performance (i.e., discovering or producing physical or intellectual property that has never been revealed).

It should be of particular interest to technology teachers to note that the pressure now on engineering educators is to develop ways to foster and assess creativity in engineering students. This pressure exists because of the demands of contemporary society and industry, which impact the engineering profession worldwide (Mitchell, 1998). In the last two decades, engineering education has focused on enhancing students' creativity to meet these various needs (Cropley & Cropley, 2000). This change has necessitated a shift away from traditional engineering curricula focused on the basic sciences such as physics, mathematics, and mechanics.

Industry now requires engineers to possess problem solving ability (Grimson, 2002). Manufacturing has changed significantly and demands that engineering majors study disciplines such as finance, management, economics, organizational psychology, and communication (Moses, 1994). When students do become engineers, many find projects out in the work place to be fragmented and the flow of information chaotic (Chan, Yeung, & Tan, 2004). This revelation may be due to many engineering students having the preconception that engineering should be intellectual in nature and involve only deductive reasoning. Because of this approach, students are severely restricted in their thinking when presented with open ended design problems that require creative thought (Court, 1998). Indeed, Chan, et al. (2004) found that a newly hired engineer, educated under the traditional engineering curricular paradigm, could take as much as six to twelve months to become professionally competent. The opportunities for technology education are clear; there is an obvious need to assist students to think creatively and look at problems in new ways.

Other approaches, although similar to the PBL blueprint, have also been used to engage students. For example, students have been challenged to design a robot to accomplish a specific task using only a certain amount or type of materials. ROBOLAB, for instance, has been found to be a powerful tool for a range of students studying these types of engineering concepts. Students are provided with a central unit or LEGO “brick” that contains several input and output devices on which they can attach touch, light, temperature, and rotation sensors. The open-ended problem posed within this framework, for example, can be to design a bumper car that can be used by a restaurant to serve meals in a limited area (Erwin, Cyr, & Rogers, 2000). Using unusual materials to construct model artifacts as solutions to problems, such as building a bridge out of ice cream sticks or spaghetti (ASCE, 2003), or using concrete to construct a boat (Johnson, 1999) have been employed as scenarios to encourage creativity in problem solving. Also, rather than suggesting unusual materials, atypical parameters have been applied to create authentic open ended problems. As an example, T. M. Lewis (2004) recounted how architecture students at the University of Liverpool were asked to design a house to reflect a piece of music. Lewis suggested that an advantage to this activity was its ability to force students to engage different senses in a creative way.

An important and significant characteristic of many of the classroom engineering and technology activities is that a portion of their appeal hinges on the competitive nature of students. In fact, competitive events are commonly tapped in order to stimulate creative ideas and innovative design in technology education classrooms and labs. Super mileage vehicle competitions (Thompson & Fitzgerald, 2006), the West Point Bridge Design Contest, FIRST Robotics Competition, FIRST LEGO League, and the Science Olympiad (Wanket, 2007) are all team based activities that are frequently mentioned in engineering and technology education literature for their ability to encourage students to work together to solve problems with specific technical parameters.

Another important curricular ingredient these events have is the ability to tap into students' emotions. Henderson (2004) commented that without seriously considering the effect of emotions, creativity could not be fully understood. Unfortunately, as demonstrated in the literature (Blicblau & Steiner, 1998; Ogot & Okudan, 2006) technology teachers do not perceive emotion as being an important part of their curriculum. However, by generating and putting into action technical problems that are either inherently motivational (i.e., profit generating and high profile for the students' school and/or community) or controversial (e.g., nuclear energy and robots in manufacturing), teachers can begin to evoke a certain amount of emotional tension that motivates students. Highly creative technology education classrooms have included these emotional and motivational influences as well as environmental characteristics (Peterson & Harrison, 2005).

It is important to note, however, that these types of events should be orchestrated carefully in order to be sensitive to the somewhat capricious nature of competitions. Specifically, it has been found that when people compete with their immediate peers, creativity appears to be reduced. Interestingly, however, when people are asked to compete with outside groups, creativity has a tendency to be fueled (Amebile, 1996). The mentioned competitive events tend to fall into this latter category and have been popular with diverse populations of students (Stricker, 2010).

An underlying significant instructional paradigm lies beneath these instructional events. Nearly all of the identified approaches hinge on the students' use of what has been termed the *creative process* (Hayes, 1990; Stein, 1974; Taylor, 1959; Torrance 1963). Hinton (1968) created the notion of *creative problem solving* by combining the creative process and the problem solving process believing that creativity would be better understood if placed within a problem solving structure. Parnes (1987) believed creativity could even be encouraged and developed through the use of steps in the creative problem solving process.

It is important to differentiate between the creative process or creative problem solving and attributes of creativity or the sub-processes of creativity (Lubart, 2000-2001). A creative process, as the name implies, is a sequence of steps a student would progress through to arrive at a solution to a problem or the production of a product. Wallas (1926) developed a model to represent such a process with four stages:

1. *Preparation.* The problem is defined while using analytical skills.
2. *Incubation.* On the surface, a person may be taking a break from the problem, but unconsciously the person is forming connections that will be revealed in the next stage.
3. *Illumination.* This stage is characterized by a sudden realization of a refined idea.
4. *Verification.* Conscious work takes place after the realization of a possible solution.

This model has endured and can still be identified in modern literature on the topic. For example, Amabile (1996) integrated a version of the four stage model in her description of the creative process. She identified five phases that included problem/task identification, preparation, response generation, response validation and communication, and finally decision making about further work.

There are factors that have been found to impede this creative process though. Duncker (1945) in his seminal work on this issue of problem solving found that *functional fixedness*, or the tendency to use objects in their usual or expected ways, could stand in the way of creative problem solving. One of the methods he used to investigate this phenomenon was to ask participants to attach a candle to a wall and light it. Materials including matches, a candle, and a matchbox filled with thumbtacks were supplied. The solution required subjects to use the matchbox as a holder for the candle by fastening it to the wall with the thumbtacks. Interestingly, the participants were more likely to solve the problem if the matchbox were given to them empty, with the thumbtacks provided separately. Providing the resources in this manner leads participants to think about the materials in atypical ways.

These PBL oriented instructional approaches offer multiple avenues for instruction and learning activities for students with diverse needs. For example, a popular and successful teaching strategy termed *differentiated instruction* asserts that students need to be accepted as they are by teachers (Tomlinson, 1999). In other words, because of the diversity of students' needs today, teachers need to be flexible in their approach and adjust to the students instead of expecting the students to adapt. Of particular interest are three salient areas that Tomlinson suggested to teachers to maximize each student's learning: *content* (i.e., what is to be taught and learned), *process* (i.e., activities used to make sense of the content), and *products* (i.e., devices that students can use to demonstrate what they learned). It is easy to see how differentiated instruction is not only sensitive to different learning styles and needs, but it offers, particularly with the context of PBL, an opportunity for each technology education student to demonstrate his or her particular strength or intelligence.

Tomlinson (1999) noted that in employing the use of products within differentiated instruction, students are able to extend their knowledge. Assessment of these products, developed as a result of employing problem based instruction, is of concern for savvy teachers and researchers alike (Michael, 2001). Some significant lessons can be learned by efforts to assess creativity in products.

Getzels and Csikszentmihalyi (1976) conducted a longitudinal study of problem finding in art. A portion of the study involved determining how art was evaluated. Their procedure involved four groups: *artist-critics*, established artists whose work was represented in museums and galleries; *artist-teachers*, all taught full time at an art school; *doctoral students in mathematics*; and *graduate business students*. Each judge was asked to rate each drawing on *craftsmanship* (i.e., technical skill of the work), *originality* (i.e., imaginativeness), and *overall aesthetic value.* Among other valuable findings, Getzels and Csikszentmihalyi found that the artist-critics group of experts appeared to base their evaluation of a work of art more on its originality than on its technical skill. The authors explained this discrepancy as a symptom of a larger misunderstanding that existed between artists and public values regarding art. Specifically, the public considers a technically accomplished piece of work as valuable. Experts, however, take skill for granted and look for other qualities; the foremost of these qualities is originality (Getzels & Csikszentmihalyi, 1976).

Some technology teachers using product based curriculum may argue that technology educator assessment would be better compared with the artist-teachers group of experts or may agree that an exceptional piece of student work is *technically accomplished*. In fact, this may be a valid argument, because Getzels and Csikszentmihalyi had the artist-teachers unknowingly evaluating their own students' work. This group rated each piece with very high consistency when compared to one another, especially in the craftsmanship category.

The context of creativity in an educational setting, the *skill* alluded to previously that is taken for granted, could also be considered the technology itself and/or the students' competent use of the technology in the classroom. Peterson and Harrison (2005) stated the technology of creativity includes tools and processes that allow a person or group to develop a solution that is original and has purpose. In other words, the mere fact that students can demonstrate the ability to competently use tools, no matter the degree of preciseness, should not qualify as a measure of creativity in a teacher's evaluation of their work.

CONCLUSION

Evidence regarding the implementation of curricular events and instructional practices aimed at fostering and supporting creativity in technology education has been encouraging. Yaşar, Baker, Robinson-Kurpius, Krause, and Roberts (2006) concluded teachers were supportive of the idea of infusing design and technology into the curriculum. However, their research also revealed that these teachers had negative perceptions of engineers generally. As demonstrated in the engineering and engineering education literature, creative thinking is the foundation to successful design within a contemporary technology curriculum. These negative perceptions may foreshadow difficulty in the full acceptance of the creativity based, engineering-focused curriculum in technology education.

This unfavorable perception could very well be the reason why contests of design and other competitive events (e.g., West Point Bridge Design Contest, FIRST Robotics Competition, FIRST LEGO League, and the Science Olympiad), which have been very effective in delivering engineering concepts to students, are chiefly extracurricular in nature (Wankat, 2007). Instead, these creative, design-based contests should be considered in the general technology education curriculum and made available to the overall student body. To do otherwise would imply that the type of creativity demanded in solving problems posed by the identified events is not important for all students and must be pushed into the realm of co-curricular activities.

Creativity pedagogical approaches in technology education are not for the faint of heart. Teachers attempting to make such a curricular shift, like that required for successful implementation of the mentioned engineering design activities, may feel uncomfortable because what they are being asked to teach is not reflected in their own educational experience (Anderson & Roth, 1989; Ball, 1996). This anxiousness can have serious implications in an environment that obviously demands flexibility and an ability to deal with novel problems that can arise (Ogle & Byers, 2000). Creativity curricular exploration, discovery, and development demand an open mind, a degree of ease with the unknown, and support.

As suggested by Tomlinson (1999), teachers that wish to implement lessons that encourage and foster creativity among their students need to have a clear idea of the content and ideas they wish to impart. They need to teach the crucial skills that students need to carry out the particulars of the hardware and software used for certain activities. More importantly, however, is their need to shape the instruction so that the students think about and understand concepts such as mathematical relationships, design, friction, force, structures, loads, mobility, mass, gravity, moments, couples, supports, simple machines, control, evaluation, prediction, problem solving, and systems.

Although a rationale and structure for the study of technology was presented to the technology education profession through the document entitled *Technology for All Americans* (ITEA, 1996), an agreed upon conceptual structure still remains unclear. However, having concepts such as design, engineering design, trouble shooting, and problem solving appear frequently in the content standards (ITEA, 2000, 2007), it seems evident that not only is the proverbial fog being lifted, but concepts related to engineering are appearing as a common theme. Indeed, it could be assumed that, as these concepts are more clearly defined or at least universally agreed upon, a concerted effort by teachers to explore novel ways of delivering these ideas can begin en masse.

REFLECTIVE QUESTIONS

1. How can a typical technology and engineering education curriculum facilitate the development of creativity in a classroom full of students with a variety of intelligences present?
2. Is there a specific type of creativity related to technological problem solving?
3. What do technology teachers perceive as challenges or constraints to implementing creativity based curricula in their classrooms?
4. What equipment, tools, and software are common to programs that have successfully fashioned creative opportunities for students in technology education?
5. Is it possible to assess creativity in technology education?

REFERENCES

Amabile, T. M. (1983). *The social psychology of creativity*. New York: Springer-Verlag.

Amabile, T. M. (1996). *Creativity in context.* Boulder, CO: Westview Press.

ASCE. (2003). They're off and clicking in 2003 bridge competition. *ASCE News, 28*(2). Retrieved from http://cedb.asce.org/cgi/WWWdisplay.cgi?135266

Anderson, C. W., & Roth, K. (1989). Teaching for meaningful and self-regulated learning of science. In J. Brophy (Ed.), *Advances in research on teaching* (Vol. 1, pp. 265-309). Greenwich, CT: Jai Press.

Ball, D. L. (1996). Teacher learning and the mathematics reforms. *Phi Delta Kappan, 77*(7), 500-508.

Besemer, S. P. & Treffinger, D. J. (1981). Analysis of creative products: Review and synthesis. *Journal of Creative Behavior, 15*, 159-178.

Blicblau, A. S. & Steiner, J. M. (1998). Fostering creativity through engineering projects. *European Journal of Engineering Education, 23*(1), 55-65.

Bruner, J. (1986). *Actual minds, possible worlds*, Cambridge, MA: Harvard University Press.

Chan, Y. C., Yeung, N. H., & Tan, C. W. (2004). InnovTech: Creativity and innovation learning facility for engineering students. *International Journal for Engineering Education, 20*(2), 261-266.

Court, A. W. (1998). Improving creativity in engineering design education. *European Journal of Engineering Education, 23*(2), 141-154.

Cropley, D. H. & Cropley, A. F. (2000). Fostering creativity in engineering undergraduates. *High Ability Studies, 11*, 207-219.

Dewey, J. (1938). *Experience and education.* New York: Macmillan.

Duncker, K. (1945). On problem solving. *Psychological Monographs, 58*(5, Whole No. 270).

Dyson, J. (1997, September). The future: A way forward for Britain. Keynote address at the Royal Academy of Engineering Visiting Professors in the Principles of Engineering Design, Annual Workshop, University of Cambridge.

Ediger, M. (2000). *State testing standards versus creativity*. Retrieved from ERIC database. (ED446139).

Erwin, B., Cyr, M., & Rogers, C. (2000). Engineer and RoboLab: Teaching engineering with LabVIEW from kindergarten to graduate school. *International Journal of Engineering Education, 16*(3), 181-192.

Felder, R. M., & Soloman, B. A. (2004). *Index of Learning Styles*. Retrieved from http://www.ncsu.edu/felder-public/ILSpage.html

Feletti, G. (1993). Inquiry based and problem based learning: How similar are these approaches to nursing and medical education? *Higher Education Research and Development*, *12*(2), 143-156.

Florida, R. (2002). *The rise of the creative class: And how it's transforming work, leisure, community and everyday life*. New York: Basic Books.

Gans, H. J. (1999). *Popular culture and high culture: An analysis and education of taste*. New York: Basic Books.

Gardner, H. (1983). *Frames of Mind: The theory of multiple intelligences*, New York: Basic Books.

Gardner, H. (1993). *Multiple intelligences: The theory in practice*. New York: Basic Books.

Gardner, H., & Hatch, T. (1989). Multiple intelligences go to school: Educational implications of the theory of multiple intelligences. *Educational Researcher*, *18*(8), 4-9.

Getzels, J. W. & Csikszenthmihalyi, M. (1976). *The creative vision: A longitudinal study of problem finding in art*. New York: Wiley.

Goleman, D. (1995). *Emotional intelligence: Why it can matter more than IQ for character, health and lifelong achievement*. New York: Bantam Books.

Goleman, D. (2006). *Social intelligence: The new science of social relationships*. New York: Bantam Books.

Goleman, D. (2009). *Ecological intelligence: How knowing the hidden impacts of what we buy can change everything*. New York: Broadway Books.

Grimson, J. (2002). Re-engineering the curriculum for the 21st century. *European Journal of Engineering Education*, *27*, 31-37.

Guilford, J. P. (1950). Creativity. *American Psychologist*, *5*, 444-454.

Henderson, S. J. (2004). Product inventers and creativity: The finer dimensions of enjoyment. *Creativity Research Journal*, *16*(2 & 3), 293-312.

Hayes, J. R. (1990, January). *Cognitive processes in creativity* (Occasional Paper No. 18). Pittsburgh, PA: Carnegie Mellon.

Hinton, B. L. (1968). A model for the study of creative problem solving. *Journal of Creative Behavior, 2*(2), 133-142.

Horwitz, R. A. (1979). Psychological effects of the open classroom. *Review of Educational Research, 49*, 71-85.

Houtz, J. C., & Krug, D. (1995). Assessment of creativity: Resolving a mid-life crisis. *Educational Psychology Review, 7*(3), 269-300.

Hunter, S. T., Bedell, K. E., & Mumford, M. D. (2007). Climate for creativity: A quantitative review. *Creativity Research Journal, 19*(1), 69-90.

Ihsen, S., Isenhardt, I., & De Sánchez, S. (1998). Creativity, complexity and self-similarity: The vision of the fractal university. *European Journal of Engineering Education*, *23*(1), 13-22.

International Technology Education Association (ITEA). (1996). *Technology for all Americans*. Reston, VA: Author.

International Technology Education Association (ITEA). (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

International Technology Education Association (ITEA). (2007). *Standards for technological Literacy: Content for the study of technology (3rd. ed.).* Reston, VA: Author.

James, L. R., James, L. A., & Ashe, D. K. (1990). The meaning of organizations: The role of cognition and values. In B. Schneider (Ed.), *Organizational climate and culture*. San Francisco: Jossey-Bass.

James, L., & Sells, S. (1981). Psychological climate: Theoretical perspectives and empirical research. In D. Magnussen (Ed.), *Toward a psychology of situations: An interactional perspective*. Hillsdale, NJ: Erlbaum.

Jane, B., & Robbins, J. (2004). Block play as a potential for learning for innovation in technology education in early childhood classrooms. In H. Middleton, M. Pavlova, & D. Roebuck (Eds.), *Learning for innovation in technology education (*Vol. 2, pp. 60-67). Surfers Paradise, Qld.: Centre for Learning Research, Griffith University.

Johnson, R. (1999, June 18). Row, row, row your (concrete) boat. *The Wall Street Journal*, Retrieved at http://www.uah.edu/student_life/organizations/ASCE/Articles/Wall%20Street%20Journal/wsjarticletext.htm

Keefe, J. W. (1979). Learning Style: An Overview. In J. W. Keefe (Ed.), *Student learning styles: Diagnosing and prescribing programs* (pp. 1-17**)**, Reston, VA: National Association of Secondary School Principals.

Kolb, D. A. (1981). Learning styles and disciplinary differences. In A. W. Chickering & Associates (Eds.), *The modern American college: Responding to the new realities of diverse students and a changing society* (pp. 232-255**)**, San Francisco: Jossey-Bass.

Kunzmann, K. R. (1995). Developing the regional potential for creative response to structural change. In J. Brotchie, M. Batty, & E. Blakely (Eds.), *Cities in competition: Productive and sustainable cities for the 21st century* (pp. 286-294), Melbourne: Longman Australia.

Lewis, T. [Ted] (2007). Engineering education in schools. *International Journal of Engineering Education*, *23*(5), 843-852.

Lewis, T. M. (2004). Creativity on the teaching agenda. *European Journal of Engineering Education*, *29*(3), 415-428.

Lubart, T. (2000-2001). Models of the creative process: Past, present, and future. *Creativity Research Journal*, *13*(3-4), 295-308.

Mahboub, K. C., Portillo, M. B., Liu, Y., & Chandraratna, S. (2004). Measuring and enhancing creativity. *European Journal of Engineering Education*, *29*(3), 429-436.

Matheson, B. (2006). A culture of creativity: Design education and the creative industries. *Journal of Management Development*, *25*(1), 55-64.

Michael, K. Y. (2001). The effect of a computer simulation activity versus a hands-on activity on product creativity in technology education. *Journal of Technology Education*, *13*(1), 31-43.

Mitchell, C. (1998). Creativity is about being free…. *European Journal of Engineering Education*, *23*(1), 23-34.

Moses, J. (1994). *Engineering with a big e: Integrate education in engineering*. MIT, School of Engineering, Cambridge, MA.

National Center on Education and the Economy. (2007). *Tough choices or tough times: The report on the new commission on the skills of the American workforce (Executive Summary)*. Retrieved from http://www.ncee.org/publications/archived-publications/tough-choices-or-tough-times-state-consortium-publications/

Ogle, T., & Byers, A. (2000). *Evaluating teacher's perceptions of technology use in the K-8 classroom.* Paper presented at the Annual Conference of the Eastern Educational Research Association, Clearwater Beach, FL.

Ogot, M., & Okudan, G. E. (2006). Integrating systematic creativity into first year engineering design curriculum. *International Journal of Engineering Education, 22*(1), 109-115.

Parnes, S. (1987). Visioneering–State of the art. *Journal of Creative Behavior, 21*(4), 283-299.

Pate-Cornell, E. (2001). Management of post-industrial systems: Academic challenge and the Stanford experience. *International Journal of Technology and Policy Management, 1,* 151-159.

Peterson, R. E., & Harrison, H. L. (2005). The created environment: An assessment tool for technology education teachers–Creativity doesn't just happen by chance; The prepared environment nourishes it. *The Technology Teacher, 64*(6), 7.

Piaget, J. (1963). *The psychology of intelligence.* New York: Routledge.

Ramey, C. T., & Piper, V. (1974). Creativity in open and traditional classrooms. *Child Development, 45,* 557-560.

Rasinen, A. (2003). An analysis of the technology education curriculum of six countries. *Journal of Technology Education, 15*(1), 31-47.

Roth, W. (1996). Art and artifact of children's designing: A situated cognition perspective. *The Journal of the Learning Sciences, 5*(2), 129-166.

Stein, M. (1974). *Stimulating creativity, Vol. 1: Individual procedures.* New York: Academic Press.

Stricker, D. R. (2010). *A case study of teaching engineering concepts in science* (Unpublished manuscript). University of Wisconsin-Stout, Menomonie, WI.

Taylor, I. A. (1959). The nature of the creative process. In P. Smith (Ed.), *Creativity: An examination of the creative process*. New York: Hastings House Press.

Teng, J. G., Song, C. Y., & Yuan, X. F. (2004). Fostering creativity in students in the teaching of structural analysis. *International Journal of Engineering Education, 20*(1), 6-102.

Thompson, J., & Fitzgerald, M. (2006). Super mileage challenge: Combining education and fun. *The Technology Teacher, 66*(1), 31-35.

Tomlinson, C. A. (1999). *The differentiated classroom: Responding to the needs of all learners.* Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

Tornkvist, S. (1998). Creativity: Can it be taught? The case of engineering education. *European Journal of Engineering Education, 23*(1), 5-8.

Torrance, E. P. (1963). Creativity. In F. W. Hubbard (Ed.), *What research says to the teacher* (Number 28). Washington, DC: Department of Classroom Teachers, American Educational Research Association of the National Education Association.

Volkerling, M. (2000). From cool Britannia to hot nation: Creative industries policies in Europe, Canada & New Zealand. *International Journal of Cultural Policy*, *7*(3), 31-44.

Vygotsky, L. S. (1962). E. Hanfmann & G. Vaker (translators). *Thought and language.* Cambridge, MA: MIT Press.

Wallace, D. B. & Gruber, H. E. (1989). *Creative people at work.* New York: Oxford University Press.

Wallas, G. (1926). *The art of thought.* New York: Harcourt Brace.

Wanket, P. C. (2007). Survey of K-12 engineering-oriented student competitions. *International Journal of Engineering Education, 23*(1), 73-83.

Welch, M., & Lim, H. S. (2000). The strategic thinking of novice designers: Discontinuity between theory and practice. *The Journal of Technology Studies*, *25*(2), 34–44.

Yaşar, Ş., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education*, *95*(3), 205-216.

Developmental Stages of Humans and Creativity

Chapter 4

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Many authors feel that educational reforms should come through the building of curricular activities around the developmental insights of men like Piaget, Bruner, Erikson, Bloom, and Maslow (Abra, 1989; Havighurst, 1972; Sevens, 1983). Although much separates these scholars in terms of analytic style and specific fields of concentration, they all seem to hold to the idea that human beings go through fairly discrete stages of development that have specific developmental needs or tasks, and that each stage calls for a rather special educational treatment. All of these men seem to be united in their belief that the maximization of human potential and creativity within the constraints of each life stage is the best way of preparing for succeeding stages (Harder, 2009; Lau & Cain, 2009; Schaefer & DiGeronimo, 2000).

WHAT IS CREATIVITY AND CREATIVE THINKING?

Erich Fromm, distinguished psychoanalyst, asserted that creativity "is the ability to see, to be aware, and to respond" (Mooney & Razik, 1967, p. 44). Fromm was quoted as stating that

> One's own powers to be aware and to respond; that is one's own creativity. To be creative means to consider the whole process of life as a process of birth, and not to take any stage of life as a final stage. Most people die before they have been fully born. Creativeness means to be born before one dies. (Mooney and Razik, 1967, p. 53)

According to the International Center for Studies in Creativity (2009),

> Creativity is an effective resource that resides in all people and within all organizations. Our more than thirty years of research has

> conclusively demonstrated that creativity can be nurtured and enhanced through the use of deliberate tools, techniques and strategies. (para.1)
>
> According to Facione (2007)
>
> Creative or innovative thinking is the kind of thinking that leads to new insights, novel approaches, fresh perspectives, and whole new ways of understanding and conceiving of things. The products of creative thought include some obvious things like music, poetry, dance, dramatic literature, inventions, and technical innovations. But there are some not so obvious examples as well, such as ways of putting a question that expand the horizons of possible solutions, or ways of conceiving of relationships that challenge presuppositions and lead one to see the world in imaginative and different ways. (p. 12)

PRINCIPLES OF CREATIVE THINKING

According to Lau and Cain (2009), there are three basic principles of creative thinking. The first principle is that new ideas are composed of old elements. New ideas are actually old ideas rearranged in a new way. The ingredients for creativity depend on the store of ideas that are available for recombination. If an individual has a limited domain of knowledge, fewer resources are available to draw from in forming new ideas. This is the reason why intellectual curiosity and a wide knowledge base can significantly enhance one's creativity. An individual has in one's possession a mixture of concepts, theories, and experience to choose from. This reason is why it is useful to try to solve a problem by consulting other people with different expertise. Creativity is not the ability to create something out of nothing, but the ability to generate new ideas by combining, changing, or reapplying existing ideas and knowledge (Barron and Harrington, 1981; Guilford, 1950).

The second principle is that not all creative ideas are the same. Creativity is not simply a matter of coming up with new ideas. The kind of creativity that is valued in society is the ability to come up with new and useful ideas, ideas that serve an important need or creates a new trend that makes an impact on society. Creativity could be divided into many domains, such as cognitive and artistic creativity. In technology and engineering education, we mostly use cognitive creativity. Cognitive creativity is a matter of coming up with solutions to practical or theoretical problems (e.g., creating a new scientific theory, launching a new product, or solving an engineering problem). It is sometimes suggested that creativity often requires going against the usual and common conventions, and that new and important ideas might be lost if one is too critical. Good critical thinking does not mean that one must always be critical. Lau and Cain (2009) asserted that it is useful to brainstorm new ideas, and sometimes it might be productive to suspend one's critical judgment and list new ideas before evaluating them.

The third principle is that creativity is enhanced by the ability to detect connections and relationships between ideas. If we want to be creative, we must be ready to explore connections between different concepts. This principle means we should have a wide and varied knowledge base. Creative people are usually those individuals who read widely, who have a great sense of curiosity, and are often willing to explore topics that do not bring about immediate benefits. Examples of creative people who read a great deal include Henry Ford, George Eastman, and Thomas Edison. As teachers we should ensure that the learning processes used are aimed at students developing a deep understanding of the connections between key concepts. Education is not simply remembering bits and pieces of unrelated information. Looking at information from different perspectives and reformulating it systematically is one way to achieve better understanding and new discoveries.

Creativity itself is a characteristic outcome of the theory of developmental stages, and the needs within those stages. Anderson (1959) asserted that Maslow thought of creativity as a "universal heritage of every human" and one that "covaries with psychological health" (p. 84). The individual who gains mental health while going through the developmental process or stages usually exhibits increasing creativity. An individual who experiences strain and anxiety while going through the different stages of life usually evidences diminished creativity (Maslow, 1954; Maslow, 1970).

The amount of creativity one possesses is a barometer of one's mental health. Anderson (1959) pointed out that Maslow elaborated on this idea when he stated that "the creativity of my subjects seemed to be an epiphenomenon of their greater wholeness and integration, which is what self-actualized implies" (p. 88). Anderson (1959) used the analogy of comparing creativity and mental health to a heated black object that radiates electromagnetic waves. At first, there is no emanation, then with increasing temperature there is heat, then light, and finally ultraviolet rays. The increase of temperature corresponds to expanded mental health, and the appearance of electromagnetic waves corresponds to creative production.

Anderson (1959) also proposed that growth creates differences within the individual that provides uniqueness. These differences are combined into new patterns giving rise to originality. This originality is intrinsic in creativity, so creativity is an outcome of the developmental process.

STAGES OF HUMAN DEVELOPMENT

There are numerous classifications and theories concerning the stages of human development and their associated developmental tasks or needs. The most common ones are from Piaget, Bruner, Erikson, Bloom, Havighurst, and Maslow. For the purpose of this chapter, the eight stages proposed by psychiatrist Erik Erikson (1950, 1959, 1968) will be used. Erickson's stages and corresponding developmental tasks align very well with the typical schooling experiences of young people. According to Warner (2000), Erickson noted that an individual's personality

> . . . is shaped by the conflict between instincts, those behaviors that are biologically predetermined and controlled, and the demands of the surrounding environment and culture, which instill behaviors that are learned. The social milieu is also fundamentally important in providing the environment from which the attitudes and efforts of individuals are shaped to use creative problem solving and apply inventive solutions to their problems. (p. 36)

Erikson (1950, 1959, 1968) asserted that the socialization process, of which creativity is a part, consists of eight stages. These stages were derived and formulated not through experimental and scientific work but through his experience in psychotherapy. Each stage is regarded by Erikson as a *psychosocial crisis*, which demands resolution before the next stage can be satisfactorily negotiated. The term "stage" as opposed to "crisis" is used throughout this chapter to present a more positive educational perspective. These stages are conceived in a scaffolding sense. Satisfactory learning and resolution of each stage is necessary if an individual is to manage the next and subsequent ones satisfactorily. Just as the foundation of a house is essential to build the first floor, the first floor, in turn, must be structurally sound to support the second story, and finally the roof.

In each of these stages or periods in life, there are developmental tasks or needs. A development task is a task that arises at or during a certain period in life for an individual to successfully complete to be happy and successful with later tasks. Failure of fulfilling successive tasks may lead to unhappiness, disapproval by society, and difficulty with later tasks (Erikson, 1950, 1959, 1968).

Erikson identified eight stages of human development that are related to different ages. One should understand that there is some variability in the ages attached to each of these stages because some people mature faster and handle these developmental tasks better than others. Erikson (1950, 1959, 1968) labeled these stages**:**

1. **Learning Basic Trust versus Basic Mistrust.** *The Hope Stage.* (Infancy: birth to 18 months)**.**
2. **Learning Autonomy versus Shame.** *The Will Stage*. (Early childhood: 18 months to 3 years).
3. **Learning Initiative versus Guilt.** *The Purpose Stage*. (Play age: 3 to 5 years).
4. **Industry versus Inferiority.** *The Competence Stage*. (School age: 5 to 12 years).
5. **Learning Identity versus Identity Diffusion.** *The Fidelity Stage*. (Adolescence: 12 to 18 years).
6. **Learning Intimacy versus Isolation.** *The Love Stage.* (Young adulthood: 18 to 35 years).
7. **Learning Generativity versus Self-Absorption.** *The Care Stage*. (Middle adulthood: 35 to 65 years).
8. **Integrity versus Despair.** *The Wisdom Stage*. (Late adulthood: 65 and onwards). This stage may start as early as age 55, depending on the individual's achievement of developmental needs in this stage and others before it (Erikson, 1950, 1959, 1968).

Harder (2009) summarized Erikson's stages as follows:

1. Learning Basic Trust versus Basic Mistrust. *The Hope Stage*

Infancy: Birth to 18 Months

Ego Development Outcome: Trust versus Mistrust

Basic strengths: Drive and Hope.

During this stage, the child, if well-handled, nurtured, and loved, develops trust and security, and a basic sense of optimism. If badly handled, the child becomes insecure and mistrustful. Erikson also referred to this period of infancy as the "oral sensory stage" where the major emphasis is on the mother's positive and loving care for the child. There is an emphasis on visual contact and touch. If successful, children learn to trust that life is basically good and they have confidence in the future. If failure is experienced, children may end up with a deep-seated feeling of worthlessness and a mistrust of the world in general. The most significant relationship in this stage is with the maternal parent, or whoever is the most significant and constant caregiver during this time (Harder, 2009).

2. Learning Autonomy versus Shame. *The Will Stage*

Early Childhood: 18 Months to 3 Years

Ego Development Outcome: Autonomy versus Shame

Basic Strengths: Self-Control, Courage, and Will.

Erikson believed the second psychosocial stage occurs during early childhood, between about 18 months to 3 years of age. The well-parented child emerges from this stage sure of himself/herself, encouraged with his/her new found control, and proud rather than ashamed of themselves. Autonomy is not, however, entirely synonymous with assured self - possession, initiative, and independence. For children in the early part of this stage, traits include stormy self-will, tantrums, stubbornness, and negativism. This is the time in life commonly known as the “terrible 2’s”. The word "no" is a common response throughout this stage.

During this stage, children start to master skills for themselves. Not only do they learn to walk, talk and feed themselves, they learn finer motor development. Self-esteem and autonomy are developed as they gain more control over their bodies and acquire new skills, and learn right from wrong. The most significant relationship is with the child’s parents (Harder, 2009).

3. Learning Initiative versus Guilt. *The Purpose Stage*

Play Age: 3 to 5 Years

Ego Development Outcome: Initiative vs. Guilt

Basic Strength: Purpose

Erikson believed that this third psychosocial stage occurs during what he called the play age or the later preschool years (from about 3 to 5 years old). In the United States, entry into formal school occurs during this stage. Children are enrolled in pre-school programs and Kindergarten. In this stage, the child learns to imagine, to broaden his/her skills through creative and active play of all kinds, including fantasy. They learn to cooperate with others, and to lead as well as to follow. If the child does not handle this stage of life properly, he/she might become fearful, to hang on the fringe of groups, continue to depend on adults, and may be restricted in the development of play skills, creativity, and imagination.

During this period, children experience a desire to imitate the adults around them and take initiative in creating play situations. Children use their creativity and imagination in playing roles in a make believe universe, experimenting with what they believe it means to be an adult. They also begin to explore the world and ask why certain things happen. The most significant relationship is with the basic family unit (Harder, 2009).

4. Industry versus Inferiority. *The Competence Stage*

School Age: 5 to 12 Years

Ego Development Outcome: Industry versus Inferiority

Basic Strengths: Method and Competence

The fourth stage is what Erikson called the school age, from first grade into middle school. Here the child learns to master the more formal skills of life and education: relating with peers according to rules; progressing from free play to play that may be structured by rules and may demand formal teamwork; and beginning to master science, math, reading, technology, and social studies concepts. Technology education and family and consumer sciences use to be solidly infused in the middle school, grades 6th - 8^{th,}, because their content, classroom activities and teaching methodology matched the developmental needs of students during the ages of about 11-13 (Sanders, 1999).

Homework in school usually becomes a requirement during this stage, and the need for self-discipline increases. The child, who because of his/her successful resolutions of earlier stages, is becoming trusting, autonomous, more creative, and displays initiative. This is a stage where creativity can be greatly developed and displayed through individual and group projects, design challenges, and other activities. The individual learns to be what Erikson called industrious. However, the unsuccessful child will doubt the future, feel lost, experience defeat, and feel inferior.

During this stage, individuals are capable of learning, creating and accomplishing new skills, knowledge, and dispositions. Erikson labeled this stage as one where an individual develops a sense of industry (Harder, 2009, para. 16). This is also a very social and emotional stage of development. If children experience unresolved feelings of inadequacy and inferiority among their peers, they can have serious problems in terms of competence and self-esteem in later life. As the world expands, the individual's most significant relationship is with his or her peers, the school, and the neighborhood. Parents are no longer the complete authorities they once were, although they are still important.

Peers become more important toward influencing the actions of the child (Harder, 2009).

The middle school experience happens during the fourth stage of development. Middle school students are in a period of tremendous transition and exploration. Education is usually not a top priority in their lives. They are more interested in their physical, emotional and social needs than they are in their intellectual needs. Peers exert increasing influence on individual decision making, attitudes, judgments, and conduct. Their ability to understand and apply abstract concepts increase and the boundaries of the world widens. It is also a time that students need to be sensitive and tolerant of individual differences and diversity in races, culture, religion, and values (Maryland State Department of Education, 1999).

5. Learning Identity versus Identity Diffusion. *The Fidelity Stage*

Adolescence: 12 to 18 Years

Ego Development Outcome: Identity versus Role Confusion

Basic Strengths: Devotion and Fidelity

The fifth stage involves adolescents from about 12 to 18 years old. The individual tries to learn how to answer satisfactorily the question of "Who am I?" However, even the best-adjusted adolescent experiences some role identity diffusion. Most boys and girls during this stage experiment with minor delinquency and rebellion. Doubts about oneself may enter their perception.

Erikson believed that during successful early adolescence, a mature perspective starts to develop. The well-adjusted young person acquires self-certainty as opposed to self-consciousness and self-doubt. He/she begins to experiment with different, usually constructive, roles rather than adopting a negative identity. The individual anticipates educational and social achievement, rather than being controlled by feelings of inferiority or by an inadequate perspective. In later adolescence, clear sexual identity - manhood or womanhood - is established. The adolescent seeks leadership, someone to inspire him/her, and gradually develops a set of ideals. In the broader culture of the United States, adolescence affords a period of "psychosocial moratorium" (Harder, 2009, para. 19), particularly for middle and upper-class adolescents. Their task is to discover who they are as individuals separate from their family and as members of a wider society. Many go into a period of withdrawing from responsibilities, thus a moratorium. Young people in this stage can experiment, trying various roles, and thus hopefully finding the one most suitable for them. Career exploration and some preparation usually take place during this stage. If individuals are unsuccessful in navigating this stage, they may experience role confusion.

Up to this stage, development mostly depends upon what is done to an individual. Starting with this stage, further development depends primarily upon what the individual does for him or herself. While adolescence is a stage at which one is neither a child nor a mature adult, life is definitely getting more complex as they attempt to find their own identity, struggle with social interactions, start thinking about a work career, and deal with moral issues.

A significant task during this stage is developing a philosophy of life. In this process, individuals tend to think in terms of ideals, which unlike reality, are usually conflict-free. The problem in this stage is that individuals do not have much real life experience and find it easy to substitute ideals for experience. Individuals develop strong devotion to friends and social causes during this stage. The most significant relationships are now with the peer group (Harder, 2009).

6. Learning Intimacy versus Isolation. *The Love Stage*

Young adulthood: 18 to 35 Years

Ego Development Outcome: Intimacy and Solidarity vs. Isolation

Basic Strengths: Affiliation and Love.

In the initial stage of becoming an adult, the individual seeks one or more companions and love. The individual tries to find mutually satisfying relationships, primarily through marriage and friendships. Most begin to start a family during this stage. Further education, including college, occurs. Career paths and preparation are determined. If negotiating this stage is successful, people can experience intimacy on a deep level, and the beginning of career success. If they are not successful, isolation and distance from others may occur. The significant relationships are with partners and close friends (Harder, 2009).

7. Learning Generativity versus Self-Absorption. *The Care Stage*

Middle Adulthood: 35 to 65 Years

Ego Development Outcome: Generativity versus Self absorption or Stagnation

Basic Strengths: Production and Care

In adulthood, this psychosocial stage demands generativity, both in the sense of marriage and parenthood, and in working productively and creatively. At this stage, career and work is most important. Individuals seek career maturity and career satisfaction. Middle-age is when individuals tend to be occupied with creative and meaningful work, and with issues surrounding family or close relationships. Middle adulthood is also when most people can expect to be in control of their life, and make decisions on their own.

The significant task during this stage is to transmit cultural values through the family and work. People in this stage are striving to establish a meaningful and stable work and home environment. Strength comes through care of others and production of something that contributes to the betterment of society, which Erikson called "generativity" (Harder, 2009, para. 26). If unsuccessful during this stage, individuals may often experience inactivity and meaninglessness.

As relationships and life goals change, the individual is faced with major life changes. Many go through a "mid-life crisis" or a "mid-career crisis", and struggle with finding new meanings and purposes in life in the later years of this stage. If individuals do not get through this stage successfully, they can become self-absorbed and stagnate. Significant relationships are within the workplace, the community and the family (Harder, 2009).

8. Integrity versus Despair. *The Wisdom Stage*

Late Adulthood: 65 to Death

Ego Development Outcome: Integrity versus Despair

Basic Strength: Wisdom

If the other seven psychosocial stages have been successfully resolved, the mature adult develops a sense of adjustment and integrity. He/she trusts others and is independent. The individual has worked hard, should have found a well-defined role in life, and has developed a self-concept with which he/she is happy with. They can be intimate without strain, guilt, regret, or lack of realism. If successful, they are proud of what they have created and achieved through their children, work, career, hobbies, and life activities. If one or more of the earlier psychosocial stages have not been resolved, individuals may view themselves and their life with despair, failure, and dissatisfaction. The stage may start earlier, somewhere between 55 and 65, depending on the individual's successful achievement of previous developmental tasks and their retirement from a career or job.

Erikson felt that much of life is preparing for the middle adulthood stage, and the last stage is recovering from it. Perhaps that is because as older adults, we can often look back on our lives with happiness and are content, feeling fulfilled with a deep sense that life has meaning, and we have made a contribution to society. This is a feeling Erikson called "integrity" (Harder, 2009, para. 29). People's strength comes from a wisdom that the world is very large and they now have a limited concern for the whole of life. Individuals phase out of work or their career, and focus on enjoying retirement, hobbies, and their extended family.

On the other hand, some adults may reach this stage and experience unfullfilment and despair, and perceive failures as they reflect back on their lives. They feel that they have not achieved their goals in life. They do not understand the true meaning of life. The significant relationship during this stage is with all of humankind, including family, friends, and society as a whole.

These eight stages of human development, or psychosocial crises, are insightful descriptions of how personality and creativity develops through a person's life. As any dedicated teacher knows, helping the individual through these various stages, and the positive learning that should accompany those stages, is a complex and difficult task. Searching for the best way of accomplishing these tasks accounts for much of the research in the field of human development and its relationship to education (Erickson, 1950, 1959, 1968; Harder, 2009).

DEVELOPMENTAL TASKS AND EDUCATION

Gowan (1972) contended that socialization and creativity of the individual is a learning-teaching process that can result in people moving from their infant state of helpless to their ideal adult state of sensible conformity coupled with independent creativity. The mastery of the lifelong tasks of learning, adjustment, and achievement are referred to in human growth and development as developmental needs or tasks. An analysis of these tasks provides a guide for the successful development of each individual. The focus is on what the individual is attempting to accomplish and is the result of the following factors: physical maturation; pressures of the cultural process; and the desires, aspirations, and values of the individual. Rarely are these factors found in isolation but, rather, in combination with one another (Gowan, 1972).

The developmental stages and their sequence provide an insight through which technology and engineering educators can promote creativity in their curriculum and teaching methods. Developmental tasks provide the basis on which educators can build a system of education to maximize the growth and integration of the emotional, social, and intellectual aspects of each individual, including creativity. The refinement of developmental tasks extends from birth to death. As stated previously, the stages of development are infancy, early and late childhood, early and late adolescence, and early, middle and late adulthood. While the first and last three stages are important, our concern here will focus on late childhood and early and late adolescence. These developmental stages occur during the time period when individuals are in school, pre-kindergarten through 12th grade, and students are involved in technology and engineering experiences.

The following brief descriptions of the pertinent developmental stages provide some key understandings for teaching creativity. Each of the developmental levels is treated separately. These descriptions provide the reader with a condensed perspective of the level, as well as relating the developmental level to the grade level.

Late childhood–5-10 years old–kindergarten to 5th grade. In this developmental stage, the child begins to recognize the fallibility of adults. He/she sees himself/herself as a child and sees adults as adults. She/he is in the process of moving to a peer-centered environment. It is at this level that development tasks among children are discernibly different. Work on these tasks starts for some children at age five (Kindergarten) and extends for some to age fifteen (grade 10).

Early adolescence–11-13 years old–middle school grades 6-7-8. This period of human development is now recognized as one of the most complex. Research has indicated that this period is crucial for the knowledge, skills and dispositions that students develop concerning oneself, education, and society in general. Problems during the high school years, such as dropping out, alcohol and drug abuse, poor academic performance, bullying, school attendance, sexual activity, and teen pregnancy, often originate during the middle school learning years (Maryland State Department of Education, 1999). Young adolescents are highly diverse in their development. They may be in different stages more than at other age periods because they enter puberty at varying ages. This affects creativity, cognitive functioning, and personality development.

These students may exhibit abrupt swings in mood and behavior: from intellectual vigor to lethargy; from strong social empathy to egocentricity; from autonomy and independence to the need for dependence on authority adults and their peers; from strong affectionate bonds with adults to displaying alienation towards adults (Howard County Public Schools, 2005).

According to the Maryland State Department of Education (1999), early adolescents need and want to

Develop a positive sense of self, as well as acceptance by peers.
Feel physically and psychologically secure.
Experience academic success.
Belong, participate and contribute to a peer group.
Feel valued and valuable to the school, family and community.
Feel like a contributing member of the group. (p. 1)

There is a wide range of individual intellectual development. Students are in a transition period, from concrete thinking to abstract thinking. They prefer active, hands-on experiences rather than passive activities. This is a good rationale for technology and engineering education at the middle school level. Students prefer interaction with peers during learning activities rather than individual activities. They prefer learning activities related to real life, authentic situations. They have a strong need for approval from their peers or the teacher. They understand high levels of humor. They might be at risk making decisions that affect their immediate academic future which may have life-long consequences. They enjoy experimentation, exploration and using their creativity to solve problems. Career awareness and career exploration are important during this stage. Students are primarily concerned with social, emotional, physical, and personal activities as opposed to educational and academic experiences (Maryland State Department of Education, 1999).

Other factors related to the middle years are that girls tend to mature physically, socially, emotionally, and intellectually about two years earlier than boys in the middle learning years. Bodily changes may cause awkward, uncoordinated behavior, and this group may be at risk to perform tasks beyond their capabilities (Maryland State Department of Education, 1999).

In this developmental stage, the adolescent begins to exhibit a strong rebellion against adults. He/she identifies with his/her peers in a new heterosexual grouping and identifies more negatively with adults. For the adolescent, there is nothing worse than trying to be an adult. Work on the early adolescence tasks may extend approximately from age eight (grade 3) through age fifteen (grade 10).

Late adolescence–14-18 years old–high school grades 9-12. In this developmental stage, adolescents are beginning to achieve identity and are trying to become adults. They have a strong desire to have others treat them like adults. Work on development tasks associated with this stage may extend into adulthood. Career development is an integral part of this stage. Students start to determine what careers they are interested in, and realize that they need to develop appropriate skills, knowledge and dispositions in their career field. Some develop these skills and knowledge through enrollment in career and technical programs at the high school level, while other wait until they enroll in a community college, four-year college or university, the military, apprenticeship training, or other training institution.

TECHNOLOGY AND ENGINEERING EDUCATION CHARACTERISTICS BY DEVELOPMENTAL LEVEL

What is best for a student should be based on the individual's growth and the developmental tasks that need to be addressed as they proceed through life. Learning success can best be initiated through activities that most appropriately address the growth and development of the individual.

The developmental activities and program characteristics that are provided in the following pages of this chapter were derived from a variety of analyses of educational guidelines, standards, and technology and engineering education activities (Atkinson, 2000; Court, 1998; Davis, McMullan and Spilka, 1998; Educational Testing Service, 2010; Gemmill, 2010; Hunter, Bedell, and Mumford, 2007; ITEA, 2000; Lewis, 2004; Maryland State Department of Education, 1979; Stricker, 2008). These activities are specifically directed toward promoting the accomplishment of the various developmental tasks, including developing creativity and utilizing it in the designed world through technology and engineering education experiences.

One of the main learning strategies being used in technology and engineering education is that of problem solving technological issues in the designed world. The Educational Testing Service (2010), in their test specifications for the PRAXIS II Technology Education test, state that students should "Know how to generate possible solutions to design problems and how to select, develop, and refine design proposals, using analysis and creativity (p. 2). Custer (1999) stated that "students need to learn how to identify and solve real problems in authentic situations" (p. 26). In problem solving, creativity is an integral part of generating ideas and possible solutions. Creative generation of solutions is one of the most exciting parts of this learning process. Critical thinking is then used to evaluate these ideas to see if they are viable options to solve the problem. By itself, creativity is not sufficient without critical evaluation. In defining invention, Custer (1999) wrote that

> Invention occurs when abstract ideas are transformed into physical objects or processes. Our world is filled with objects that first existed in the imagination of creative people. Through a process of development, they assumed the forms that we find useful. Important examples of inventions include the first electric light bulb (Edison), the moving assembly line (Ford), interchangeable parts, and even the wheel. (p. 27)

Design and problem solving have been the focus of many activities that take place in today's technology and engineering education laboratories. Through simulations, design challenges, and engineering design briefs, students learn how to use initiative and creativity. Custer (1999) asserted that

> For many students, design and problem-solving experiences provide an opportunity to develop ingenuity and creativity. There is something about getting something to work or turning abstract ideas into tangible objects that builds self-confidence and enhances creativity. (p. 32)

The importance of creativity and design in technology and engineering education is reflected throughout the *Standards for Technological Literacy* (*Standards*; ITEA, 2000). This publication emphasized the importance that creativity and design play in the creation, use, and study of technology and technological systems. *Standards* placed creativity firmly at the core of the design process. Pink (2005) advocated the need of creativity and design in education and asserted that we are moving from the computer-generated Information Age to the Conceptual Age. He stated that "The future belongs to a different kind of person with a very different kind of mind – creators and empathizers, pattern recognizers, and meaning makers" (p. 1).

The following items as they are listed do not in any manner or form constitute a program for students in technology and engineering education. The activities and tasks are by no means all inclusive but a sample of what can be done in the technology and engineering classroom and lab. The set of characteristics is actually a listing of the kinds of student involvement that are recommended to be woven into a program along with content and teaching processes.

The various items of student involvement are listed under a series of headings that have a relationship to developmental tasks associated with the three developmental periods or levels of student growth from Kindergarten through the 12th grade. The traditional stages have been slightly modified to align with the typical schooling structure in the United States: elementary school, middle school, and high school. It should be noted that there is carry-over and cross-over of many developmental tasks based on the individual's maturity and success in the previous stage of development. Each of the stages of student growth contains various developmental activities.

Late Childhood–5-10 Years Old–Elementary School, Kindergarten-5th Grade.

Individuals in this stage are involved in

Meeting adult expectations for restricting exploration and manipulation of an expanded environment. The students:

- Start to explore the new world of things as found in technology and engineering education activities, which include simple tools, equipment, and materials.
- Explore their capabilities, likes, and interests related to the objects, processes, and activities in the technology and engineering education laboratory.
- Begin to work within the limitations, rules, and guidelines associated with technology and engineering education activities.

Improving the use of the symbol and language system. The students:

- Learn new words and concepts associated with the tools, materials, and processes found in their technology and engineering education experiences.
- Discuss the projects and assignments they are involved in.
- Create simple sketches to illustrate ideas, objects, or materials.
- Begin to develop relationships and understand the transfer between two-dimensional drawings and three-dimensional objects.
- Use language to give directions or assistance to other students in the pursuit of technology and engineering education activities.
- Develop simple and brief reports about their technology and engineering education activities.
- Learn to use language to communicate with others their ideas, problems, successes, and plans associated with their technology and engineering education experiences.
- Start to use basic instructional technology, including computers, the Internet, and PowerPoint presentations to convey technological information.

Developing the ability to interact with classmates. The students:

- Begin to share creative ideas and materials with others in the class.
- Begin to see that they must wait their turn and share in the use of particular materials, tools or equipment.
- Begin to work in a team to creatively solve problems and make simple things.
- Work on individual projects in association with other students carrying on similar activities.
- Work as a member of a creative team to make something.
- Construct things and solve problems of value to the group.

Taking directions and being obedient in the presence of authority. The students:

- Take directions from the teacher in the planning and completion of their assignments and projects.
- Take directions in creatively solving problems and the construction of their projects.
- Obey classroom and lab ground rules set up to govern the technology education and engineering activities.
- Obey safety rules and regulations.
- Assist the teacher in organizing the technology lab.
- Seek advice and approval from the teacher for the planning and construction of projects in technology and engineering education activities.
- Imitate the teacher's skills, knowledge and procedures in conducting technology activities.

Adjusting to expectations resulting from improving motor abilities. The students:

- Learn to use materials, basic tools and simple equipment in the process of developing their motor and muscular capabilities.
- Gain insights into their motor and muscular capabilities through the use of tools and materials.
- Adjust to the teacher's expectations of their motor and muscular capabilities in working with tools and materials in an organized manner.
- Experience a variety of different manipulative opportunities to develop their motor and muscular capabilities in keeping with their individual interests and creativity.
- Begin to coordinate their small muscles with the large muscles in various shaping, forming, fabricating, and finishing activities such as putting parts together or assembling, and drawing objects or designs.

- Use their fine or small muscles in learning about the qualities of materials to make things such as smoothness, roughness, hardness, softness, heaviness, and lightness through a variety of activities in technology and engineering education.
- Continuously refine their use of instructional technology, such as computers and handheld devices, for communication and educational activities.

Developing a notion about one's place in the cosmos. The students:

- Start to develop an understanding of the characteristics and scope of technology and the designed world.
- Start to develop an understanding of the core concepts of technology.
- Seek and accept answers to problems from others pertaining to the technology and engineering education activities.
- Explore for themselves selected areas of curiosity with respect to problems, tools, materials, processes, and equipment.
- Experience diverse opportunities to explore materials, processes, and tools that may be unique to the individual.
- Engage in diverse opportunities to creatively explore themselves in terms of interests, abilities, understandings, and attitudes.

Elaboration of the concept pattern. The students:

- Learn the basic functions of technology.
- Learn what people do with technology.
- Pursue the "why" of technological concepts, things, objects, tools, materials, and processes commonly found in the technology and engineering education activities.
- Broaden their understanding of why things work.

Decision making and reasoning. The students:

- Are capable of learning, creating and accomplishing numerous new skills and knowledge in reading, writing, science, and math, thus developing a sense of industry.
- Increasingly makes decisions about their role in class, solving problems, making things, and learning about materials or processes to be used.
- Still seek assistance from the teacher and other adults in educational activities.
- Start to develop standards of performance and personal involvement in the problem solving aspects within the technology and engineering education laboratory and classroom.

- Formulate and participate in the development of safety and class management rules by which the class and the laboratory will be governed.
- Are introduced to the technological method of problem solving as a process for solving technological problems in society.
- Make deductions about the nature of technology based on direct observation and use.
- Are permitted and encouraged to establish creative and alternative ways to carry out a class activity.
- Accept the responsibility of the outcomes of their decisions.
- Experiment with various processes to determine their appropriateness to the task at hand.
- Search for creative reasons why core technologies and materials behave as they do.

Sharing and working together. The students:

- Move from free play in early childhood to a more structured activities governed by rules and procedures in late childhood.
- Begin to work in small and large group activities associated with the study of technology.
- Work on simple projects and assignments as a problem-solving team.
- Work with other students in the carrying out of cooperative problems related to core technologies.
- Team up with other students to work on projects that extend beyond the capabilities of individual effort.
- Share ideas and plans with other students in the formulating of laboratory activities.
- Give assistance to peers experiencing difficulties on matters with which they have had similar problems.

Exploration. The students:

- Manipulate tangible things in the classroom and lab in an effort to test themselves, as well as the items being manipulated.
- Display more creativity, initiative and autonomy in exploring technology and the world around them.
- Engage in the process of exploring and experimenting with instructional technology computers, digital cameras, handheld devices, and other technologies.
- Explore the designed world of technology to determine its function, operation, and usefulness.

- Are exposed to a wide variety of processes and materials to broaden their perceptions regarding the physical and chemical characteristics of these materials.

Leadership and communication. The students:

- Are starting to take on leadership roles in the development of a technology and engineering activity but still rely on the teacher's and adult guidance and advice.
- Are given opportunities in the laboratory activities to set performance standards, engage in decision making, set goals, evaluate each other, and perform limited leadership roles.
- Learn to use language and writing to communicate using instructional technology with others regarding the nature of work.

Judgment and value making. The students:

- Start to develop a value system related to technological systems and the designed world.
- Make value judgments regarding right or wrong answers, procedures, and materials.
- Develop more objectivity about decisions required in the pursuit of technology and engineering education activities.

Personal and social identification. The students:

- Start to search for security, belonging, acceptance, and recognition through peer groups that are formed to carry out the work of a team.
- Develop forms and modes of student dress consistent with peer group identification.
- Play roles that are associated with their creative aspirations.
- Join others in the forming of working groups associated with class activities.
- Determine outcomes in the consideration of issues or problems that relate to technology.

Early Adolescence–11-13 Years Old–Middle School, Grades 6-8. Individuals in this stage are involved in

Decision-making and reasoning. The students:

- Understand the relationships among technologies and the connections between technology and other fields of study.
- Understand the cultural, social, economic, and political effects of technology on society.
- Can explain the effects of technology on the environment.
- Know the role of society in the development and use of technology.
- Understand the influence of technology on history.

- Apply core concepts of technology to creatively solve problems.
- Are more interested in their physical, social, emotional, and psychological needs than educational and intellectual needs during middle school.
- Make decisions about their role in class, problems to solve, and materials or processes to be used.
- Develop standards of performance and personal involvement in the construction or organizational aspects of technology and engineering education.
- Develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.
- Develop an understanding of the creative attributes of design and engineering design.
- Apply the design process to solve problems.

Controlling and using a new and changing body. The students:

- Are rapidly changing physically during this period, affecting their social, sexual, and psychological outlook on education and life.
- Engage in such activities as lifting, carrying, holding, and transferring without the assistance of others, and in association with others.
- Engage in a variety of manipulative activities building things, testing things, and analyzing things in the technology and engineering lab.

Establishing independence from adults. The students:

- Want to do things on their own and make their own decisions.
- Select areas of study to be pursued in the technology and engineering education classroom and laboratory.
- Select a problem, project or a technological development to be solved, constructed, and/or studied.
- Solve a problem and investigate sources of information for their problem or project, independent of the teacher's control.
- Lead a seminar or a large group discussion with one's peers.
- Play a leadership role in solving problems.
- Make independent decisions about processes and tools to be used in solving a problem.
- Make plans for projects or activities associated with leadership roles.
- Make limited requests for assistance on a project or problem from the teacher.
- Plan and carry out increasingly larger parts of the educational activities and requirements independently or with peers.

- Pursue their work on engineering challenges, problems, and projects with a minimum of consultation with the teacher or other adults.
- Look to their fellow students for gratification related to their accomplishments in the technology and engineering education laboratory. Peers or classmates are exposed to each others' accomplishments from planning, constructing, developing, and building things.

Behaving according to shifting peer codes. The students:

- Perform in leadership and followership capacities in laboratory activities which emphasize creative group or team interaction activities.
- Help each other in the performance of their work on problems, challenges, projects, assignments, or reports.
- Join with others in attempting to arrive at solutions to problems growing out of the educational activities.
- Participate in role activities related to various responsibilities when serving on a creative design team.
- Engage in peer evaluations related to problems and progress in carrying out activities.
- Rely on peers for assistance with work on problems associated with work or problems associated with information sources, tools, or equipment to be used, things to do, and procedures to follow.
- Assist each other in the development of their design challenges, projects, displays, or construction activities.
- Assist each other in carrying out their management or followership roles in activities.
- Perform a leadership role in the management of class activities.

Student acceptance of one's self as a worthwhile person. The students:

- Assume leadership and team roles in a technology or engineering activity.
- Assist other students in the planning, development, and construction of their projects.
- Describe various personnel achievements in the pursuit of a project or a role on the personnel chart in business or industry.
- Lead and/or participate in seminar sessions.
- Take on different roles or assignments working with others.
- Receive assistance from fellow students in the planning, researching or constructing of their projects.
- Play roles that will enable them to assist others in carrying out their tasks or assignments.

- Volunteer to share experiences, information, or materials with other students in the pursuit of their projects or class assignments.

Moving from the concrete to the abstract and applying general principles. The students:

- Generalize regarding their concrete experiences in the technology and engineering education program with reference to such concepts as problem solving, engineering design, manufacturing, construction, automation, management organization, productivity, technology, and technological impact.
- Develop ideas and rationalizations related to the problems and contributions of a society dominated by technology and technological systems.
- Define and describe terms and conditions associated with the study of technology and the designed world.
- Explain in a logical manner the results, products, and happenings associated with the development and functioning of technology.
- Use the experiences of the laboratory to provide the background for verbal and written explanations and interpretations related to incidents, events, and actions common in a technological society.
- Discuss in abstract terms those understandings and perceptions that result from the concrete and realistic experiences of the laboratory.
- Learn to use language and the written word more effectively and fluently as they discuss their first-hand experiences in the classroom and laboratory.
- Explain and identify casual factors associated with such items as the quality of products, environmental issues, and product costs.

Utilization of more sophisticated and creative language and communication techniques. The students:

- Learn to use more elaborate and creative oral and written communication to describe, clarify, or communicate increasingly complex relationships with respect to industrial, business, or technological organizations in the designed world.
- Become more elaborate and creative in their use of instructional technology, including webpages, PowerPoints, and webquests.
- Analyze processes and problems associated with the study of technology and the designed world.
- Communicate ideas or concepts related to the products and/or contributions of technology.
- Communicate the ideas or concepts related to the development of technology.

- Learn to use their creative drawing or graphic illustration capabilities using a variety of computer programs to describe, clarify, or communicate increasingly complex technological solutions.
- Learn to use multiple intelligences such as their spatial, visual, dramatic, linguistic, or auditory capabilities to express, describe, illustrate, or clarify increasingly complex concepts, ideas, problems, or conditions related to the products and contributions of technology.

Identification with one's peers. The students:

- Need to belong, participate and feel like a contributing member to a peer group in educational and social activities.
- Select projects or activities that have a relationship to one's peer group in class, in school, and in society.
- Align themselves with peers on discussions or challenges relating to product selections, role positions, class procedures, and responsibilities.
- Involve themselves on working committees in group projects.
- Seek assistance from peers relative to the solution of problems, gathering of materials, helping with processes, and defining roles in the various activities.
- Request opinions or approval from peers regarding procedures, selections, accomplishments, plans, or proposals related to activities in which they are involved.

Late Adolescence–14-18 Years Old–High School, Grades 9-12. Individuals in this stage are involved in

Problem-solving and assessing outcomes. The students:

- Use the problem solving method to define issues, create possible solutions, collect data, and determine creative solutions in the designed world.
- Creatively generate ideas or solutions to technological problems and critically evaluate these solutions.
- Experiment with various processes to determine their appropriateness in solving problems.
- Strive to establish the basis for the logical pursuit of product design and/or production.
- Develop abilities to apply the design process to creative problem solving.
- Use and maintain technological products and systems.
- Assess the impact of products and systems on society.

- Analysis the environmental, cultural, social, economic, and political effects of technology.
- Analyze the role of society in the development and use of technology.
- Analyze the influence of technology on history.
- Understand the role of troubleshooting, research and development, invention and innovations, and experimentation in problem solving.
- Endeavor to establish a logical resolution regarding right and wrong in the areas of technological systems and their relationship to environmental issues, labor issues, profits, mechanization, automation, capitalism, safety, and human relations.
- Explore a variety of roles in a business or industrial personnel management organization in search of possible career options.
- Go beyond the teacher's answers in the search for solutions to technological problems in the designed world.
- Learn to use their technology experiences to establish a clear perception of their academic and technical capabilities, interests, weaknesses, and strengths.
- Examine various products through reverse engineering.
- Use research and experimentation procedures to assess product design and performance.
- Learn to use their technology and engineering experiences to develop a self concept appropriate with their performance in the area.

Reasoning and decision making. The students:

- Make an analysis of the kinds of preparation necessary to perform one or more roles in the designed word of information and communication, construction, manufacturing, energy and power, agriculture and related biotechnologies, transportation, and medical technologies.
- Select and use different technologies in information and communication, construction, manufacturing, energy and power, agriculture and related biotechnologies, transportation, and medical areas.
- Make decisions regarding product development on the basis of considered alternatives and options.
- Learn to use judgment in the development of procedures and processes to be used in the pursuit of a technology activity.
- Exercise judgment in carrying out leadership roles in various class activities.
- Learn to use creative and critical thinking and logical reasoning in reaching conclusions in engineering design activities.

- Engage in the process of establishing the rules and policies to be followed in the development of student-managed group studies of technological systems.
- Generalize about the merits of the various positions of labor and management in the contemporary conceptual innovation age and our highly technological society.
- Take positions on the contributions and/or problems attributed to technology on society.
- Join with other students in establishment of work standards associated with various forms of problem solving and project development in the laboratory.
- Make creative decisions about the values and contradictions of modern technological practices.
- Rationalize the values or merits of a technological society.

Career exploration and selection. The students:

- Explore various career roles and make career selections in information and communication, construction, manufacturing, energy and power, agriculture and related biotechnologies, transportation, and medical technologies.
- Interview personnel in business or industry relative to their career roles.
- Develop specific knowledge, skills, and dispositions relative to potential career choices through technology and engineering education activities.
- Enter into discussions of occupations and career choices relative to possible future occupations.
- Explore their career interests.
- Explore their capabilities in performing various skills and operations associated with technology.

Citizenship and preparing to accept one's future adult roles. The students:

- Develop attitudes and values related to the work performed by various careers involved with technology through experiencing the work of such persons.
- Perform the role of an engineer, technician, or researcher.
- Develop insights into social and economic problems associated with the present society through involvement in various kinds of experiences similar to those in different technological fields.
- Assume positions of responsibility in various class activities.

- Assume responsibility over others in the various management roles of a technology and engineering enterprise conducted in the laboratory.
- Visit technology and engineering firms in order to develop deeper insights into the conditions of work, nature of production, capital investment, job opportunities, safety factors, and other related issues.
- Discuss the nature of contemporary technology enterprises in the fields of information and communication, construction, manufacturing, energy and power, agriculture and bio-technology, transportation, and medical technologies, and their relationship to human values, profits, community contributions, and other environmental factors.

Gemmill (2010) proposed the following:

- Creating solutions to open-ended technological problems and challenges.
- Designing, modeling, prototyping, producing, and servicing technological innovations and systems.
- Contributing to a student-centered, democratically managed, technological enterprise.
- Communicating views of technology, accommodating viewpoints of others, and debating critical society and technology issues.
- Assessing the evolution of technology and forecasting future creative developments.
- Developing ethical perspectives on the creation, uses, and impacts of technology.
- Participating in technology and engineering student organization governance, competitive events, and community service activities.
- Enjoying the use and study of technology.
- Making rational, holistic, and responsible technological choices and decisions.

Establishing one's independence in an adult manner. The students:

- Experience adult roles in the development and implementation of class or laboratory activities.
- Experience the reality of the adult world through activities carried out in the classroom and laboratory.
- Carry out assignments and creatively solve problems on their own.
- Make judgments regarding the roles and activities in technology.
- Perform various tasks normally assumed by the teacher.
- Assist in class management, organization, and control.
- Assist in determining class and laboratory ground rules, policies and routine.

- Assist in helping and instructing other students in the laboratory.

Adopting adult-patterned social values and learning new peer codes. The students:

- Work in small groups and as a team to carry out projects and activities.
- Establish various levels of responsibility in the carrying out of technology activities.
- Identify with a particular level in a research and engineering group, a production team, or the management side of a technological enterprise.

CONCLUSION

In order to be effective technology and engineering educators, and to promote the concept of creativity in technology and engineering education, one must understand and anticipate the physical, intellectual, emotional, and social developmental needs of students. This chapter presented the concept of utilizing developmental stages and corresponding tasks or needs to help design technology and engineering education programs and curriculum. Creativity is an aspect in all of these developmental stages, and this concept relates to many of these individual developmental needs. There are different levels of creativity involved in these developmental stages and tasks. The developmental approach as a basis for program development and promoting creativity will ensure that students progress from class to class, Kindergarten to high school, in a meaningful and authentic way. The important thing for teachers to do is meet the developmental needs of students as they learn the knowledge, skills, and dispositions associated with technological systems in the designed world.

REFLECTIVE QUESTIONS

The following reflective questions are for educators to consider:

1. How can developmental tasks or needs be use by technology and engineering education teachers to design meaningful learning activities to promote creativity?
2. What learning activities can technology and engineering educators design to promote creativity based on the developmental needs of students?
3. How do creativity tasks vary from developmental stage to developmental stage?
4. How can differentiated instruction be used to serve the creative needs of a diversity of students?
5. How can an understanding of developmental stages and developmental needs and tasks help technology and engineering educators plan and implement a curriculum that is developmentally appropriate, one that helps insure student success, and promotes life-long learning?

REFERENCES

Abra, J. (1989). Changes in creativity with age: Data, explanations, and further predictions. *International Journal of Aging and Human Development, 28*(2), 105-26.

Anderson, H.H. (1959). *Creativity and its cultivation*. New York: Harper Brothers, 1959.

Atkinson, S. (2000). Does the need for high levels of performance curtail the development of creativity in design and technology project work? *International Journal of Technology and Design Education, 10*(3), 255-281.

Barron, F. and Harrington, D.M. (1981). Creativity, intelligence and personality. *Annual Review of Psychology, 32*, 439-476.

Boden, M. A. (1991). *The creative mind: Myths and mechanisms.* New York: Basic Books.

Child Development Institute. *Stages of social-emotional development in children and teenages.* Retrived December, 2009 from http://www.childdevelopementinfo.com/development/erickson.shtml.

Court, A. W. (1998). Improving creativity in engineering design education. *European Journal of Engineering Education, 23*(2): 141-154.

Custer, R.L. (1999). Design and Problem Solving in Technology Education. *NASSP Bulletin, 83*: 24-33.

Davis, M., Hawley, P., McMullan, B. and Spilka, G. (1998). *Design as a Catalyst for Learning*. Alexandria, VA: Association for Supervision and Curriculum Development, pp. 1-15.

Davies, T. (2000). Confidence! Its role in the creative teaching and learning of design and technology, *Journal of Technology Education, 12*(1), 18-31.

Educational Testing Service. (2010). *Praxis II Technology Education - Test at a Glance*. Princeton, New Jersey.

Erikson, E. H. (1950). *Childhood and Society*. New York: Norton.

Erikson, E.H. (1959). *Identity and the Life Cycle*. New York: International Universities Press.

Erikson, E. H. (1968). *Identity, Youth and Crisis*. New York: Norton.

Facione, P. (2007). *Critical thinking: What it is and why it counts?* Millbrae, California: California Academic Press. Retrieved from http://free.uwc.ac.za/ripmixlearners/_media/tracey:media:what_why2006.pdf

Florida, R. (2007). *The flight of the creative class: The new global competition for talent*. New York: Collins.

Florida, R. (2002). *The rise of the creative class*. New York: Basic Books.

Gemmill, P. (2010). *Action-oriented technology education contributions to citizenship skills*. Presentation at the ITEA International Conference, Charlotte, North Carolina.

Gowan, J. (1972). *Development of the creative individual*. San Diego, California: Robert K. Knapp.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5*, 444-454.

Harder, A. (2009). *The Developmental Stages of Erik Erikson*. Retrieved December, 2009 from http://www.learningplaceonline.com/stages/organize/Erikson.htm

Havighurst, R. (1972). 3rd ed. *Developmental tasks and education*. New York: Random House.

Howard County Public Schools. (2005). *The middle school student: roots and wings, the in-between-ager*. Ellicott City, Maryland: Author.

Hunter, S. T., Bedell, K. E., and Mumford, M. D. (2007). Climate for creativity: A quantitative review. *Creativity Research Journal, 19*(1): 69-90.

International Center for Studies in Creativity. (2009). *Creativity resources.* Retrieved January, 2010 from http://www.buffalostate.edu/creativity/x599.xml?bpid=142

International Technology Education Association. (2000). *Standards for technological literacy:Content for the study of technology*. Reston,VA: author.

Lau, J. and J. Cain. (2009). *Creative thinking module*. Retrieved January, 2010 from http://philosophy.hku.hk/think/critical/resources.php

Lewis, T. M. (2004). Creativity on the teaching agenda. *European Journal of Engineering Education. 29*(3): 415-428.

Lubart, T. (2000-2001). Models of the creative process: past, present, and future. *Creativity Research Journal, 13*(3&4), 295-308.

Maryland State Department of Education. (1979). *Industrial Arts: Guidelines for Program and Facilities for the State of Maryland.* Baltimore, Maryland: Author.

Maryland State Department of Education. (1999). *What Matters in the Middle Grades.* Baltimore, Maryland: Author.

Maslow, A. H. (1954). *Motivation and personality*. New York: Harper and Row.

Maslow, A. H. (1970). 2d ed. *A theory of human motivation: motivation and personality*. New York: Harper and Row.

Michalko, M. (1998). *Cracking creativity*. Berkeley, CA: Ten Speed Press.

Mooney, R. L. and Razik, T. A. (eds). (1967). *Explorations in creativity*. New York: Harper and Row.

Pink, D. H. (2006). *A whole new mind: Why right-brainers will rule the future*. New York: Riverhead Books.

Ramey, C. T. and V. Piper. (1974). Creativity in open and traditional classrooms. *Child Development, 45,* 557-560.

Sanders, M. E. (1999). Technology education in the middle school: Its role and purpose. *NASSP Bulletin, 83,* 34-44.

Schaefer, C. E. and T. F. DiGeronimo. (2000). *A parent's guide to normal childhooh development ages and stages*. New York: John Wiley & Sons.

Stevens, R. (1983). *Erik Erikson: An Introduction*. New York: St. Martin's.

Stricker, D.R. (2008). *Perceptions of creativity in art, music and technology education* (Unpublished doctoral dissertation). University of Minnesota, Twin Cities.

Tornkvist, S. (1998). Creativity: can it be taught? The case of engineering education. *European Journal of Engineering Education*, *23*(1), 5-8.

Torrance, E. P. (1975). Creativity research in education: Still alive. In I.A. Taylor and J.W. Getzels (Eds.), *Perspectives in creativity* (pp. 278-296). Chicago: Aldine.

Warner, S. A. (2000). *The effects on student's personality preferences from participation in Odyssey of the Mind* (Unpublished doctoral dissertation). West Virginia University, Morgantown, West Virginia.

Weisberg, R. W. (1999). Creativity and knowledge: A challenge to theories. In R.J. Sternberg (Ed.), *Handbook of Creativity* (pp. 226-250). New York: Cambridge.

The Creative Brain

Chapter 5

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Creativity is one of the most important of human attributes. Creativity has enriched peoples' lives, prolonged human life, and has helped to relieve suffering. When my mother was born in 1903 the Wright brothers had not yet flown their plane and there were neither antibiotics, nor refrigerators. When she died at the age of 89, not only were people traveling by jets, humans had even been to the moon. Homes had air conditioning, food was being stored in refrigerators, and people were eating prepared meals by heating them in a microwave.

In addition to improving the human condition and enriching peoples' lives, creativity also has economic implications. For example, in his book, *The Rise of the Creative Class*, Florida (2002) noted that countries such as the United States cannot compete with other less affluent countries in the inexpensive labor market. Both today and in the future, the American economy will be heavily dependent on people who are creative. These people will, undoubtedly, be the most successful in an increasingly global economy. This chapter will provide a brief overview of how the human brain mediates acts of creativity. However, before discussing the brain mechanisms that are involved with creativity, it will be helpful to first define this construct.

DEFINITION OF CREATIVITY

The American Heritage Dictionary of the English Language (Pickett, 2006) defined creativity as "productive; creating" and "characterized by originality" (p. 427). Bronowski (1972) defined creativity as the ability to find unity in what appears to be diversity. As an example of what this definition means, a person spending several weeks with a word processor randomly typing letters would have produced many words. This process would create a very novel-original product. However, few people would consider this written work creative. Additionally, while all the words typed by this person were productive and novel, unity would not be present.

Great scientists, such as Copernicus, Darwin, Einstein, and Newton, developed theories that allowed people to see the order in what appeared to be disorder. By suggesting a heliocentric system, Copernicus was able to explain the motion of the planets. Darwin explained the myriad forms of life currently present on Earth by suggesting that animals evolved based on their ability to survive, while other less successful forms have become extinct. Great creative art works such as paintings, in addition to being novel, often have a myriad of colors, shapes, and textures. In these great paintings all this diversity also has unity. This same rule holds true for great pieces of music and literature.

As will be discussed in this chapter creativity requires more than *finding unity*. This finding has to be new and the creative person must also produce a creative work. Thus, creativity is defined for this chapter as "the ability to understand, develop and express in a systematic fashion, novel orderly relationships" (Heilman, Nadeau, & Beversdorf, 2003, p. 369).

STAGES OF CREATIVITY

Creativity can be difficult to define because it is a process with multiple ways of accomplishing an end goal. As a process, creativity takes place in organized stages. Helmholtz (as cited by Eysenck, 1995) first proposed a multi-staged approach to creativity in the late 1800s. Wallas (1926) later refined this model to be inclusive of the following stages:

1. *Preparation* is the initial stage in which a person develops the knowledge and skills needed to discover and produce a creative product.
2. *Incubation* is the stage before the new discovery of the unity, where a person's brain either consciously or subconsciously searches for unity.
3. *Illumination* is the finding of unity, which is sometimes called the *ah-ha* experience. Legend has it that when Archimedes discovered the law of buoyancy in the bathtub he yelled *Eureka*. For Archimedes this was an *ah-ha* experience. Sometimes when the prepared mind sees an anomaly it helps to produce an illumination. For example, Fleming observed that a mold which flew through his window and landed on his bacterial cultures killed the bacteria he

was growing in his laboratory. Although Fleming's discovery of penicillin was based on an anomaly, it was his *prepared mind* that enabled him to see the importance of his observation. The generation of creative ideas, however, often does not require great leaps or the *ah-ha* experience. Therefore, the incubation and illumination stages could be combined into one stage called *innovation.*

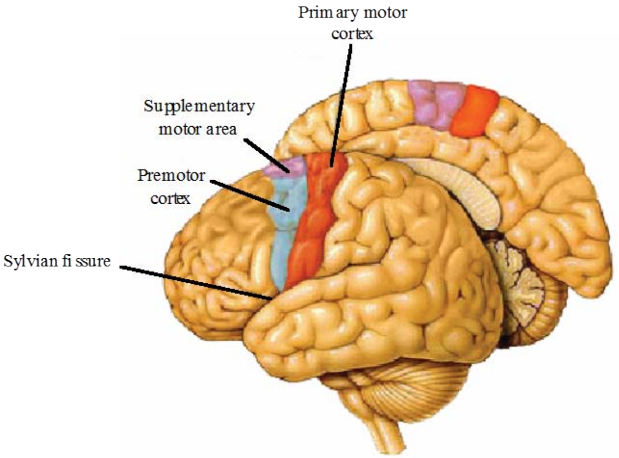
4. *Verification and Production* is the final stage in which the creative scientist, engineer, technologist, or designer tests a new theory or idea, and publishes the results. Similarly, the visual artist, composer, author, or choreographer, produces the artistic works.

PREPARATION FOR CREATIVITY

As mentioned in the introduction, there are various brain mechanisms that contribute to human creativity.

Conceptual knowledge and procedural memory. There are several forms of memory, including episodic memory, semantic memory (also call conceptual knowledge), and procedural memory. Recalling matters of whom, when and where are all examples of episodic memories. For example, recalling what you had for dinner last night is a form of episodic memory. Episodic memories are mediated in the brain by elements of the Papez circuit including the hippocampus, fornix, mammillary bodies, thalamus, and retrospenial cortex. The formation of episodic memories is dependent upon the neurotransmitter acetylcholine (a brain chemical), and the cerebral hemispheres. The cells of origin for this neurotransmitter system are in the basal forebrain. Semantic memories (conceptual knowledge) are the representations of the information we have stored in our brains. There are many forms of knowledge stored in the human brain. For example, knowledge of propositional language includes the ability to speak, understand, read and write, the ability to calculate using numbers, the use and understanding of directions and routes, and the recognition of peoples' faces. Procedural memories are memories of how to perform a learned skill, such as riding a bike, hitting a golf ball, using a power tool, or operating the controls of an automobile. Procedural memories, such as learned motor skills, appear to be stored in the basal ganglia-frontal cortex regions (pre-motor cortex; see Figure 1, next page). Each of these systems appears to be both interactive and independent of each other. For example, Verfaellie, Croce, and Milberg (1995) recounted the story of H. M. who had his hippocampi removed and lost his ability to form episodic memories; however, H. M. was still able to learn new motor skills. These authors provided additional examples of other people with hippocampal damage who, despite profound amnesia (episodic memory deficits), were able to maintain and add to their semantic-conceptual memories.

Figure 1. The Cortex Areas of the Brain Associated with Procedural Memories



Note. Adapted from an image found at *The Brain from Top to Bottom* web site, which was funded through the Canadian Institutes of Health Research: Institute of Neurosciences, Mental Health and Addiction. Used within copyleft ©guidelines. Accessed on June 21, 2010 at http://thebrain.mcgill.ca/flash/a/a_06/a_06_cr/a_06_cr_mou/a_06_cr_mou.html

Depending on the type-domain of creativity, creative people possess both stored conceptual knowledge and skilled behaviors. Their creativity is influenced by their ability to manipulate their conceptual knowledge (Heilman, 2005, p. 114). Their skilled performances are not based on the use of stored conceptual knowledge, but instead rely on procedural memories (p. 53), which might not contribute to creative innovation (p. 57). While conceptual memory can be developed quickly with as little as one exposure to the content, skills rely on procedural memories that require practice and feedback. Procedural memories are more easily learned in childhood (p. 56). Thus, many talented performers developed at an early age the procedural memories that are required for their special talents. Throughout their lives they then call upon those procedural memories to refine and enhance their skills and creative abilities.

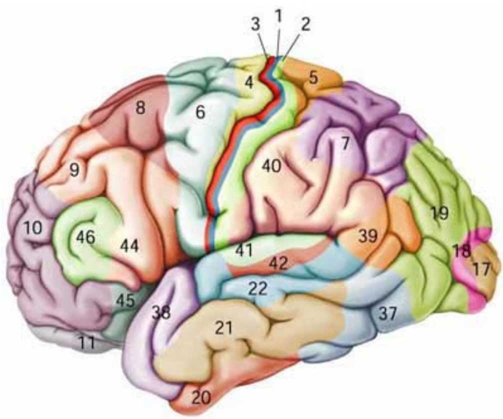
Intelligence. The term *intelligence* also has many definitions. Some cynics define intelligence as the score obtained on an intelligence (IQ) test. Historically, many of the people who helped develop IQ tests were attempting to test creativity. People with very high IQs (over 140) were even termed *geniuses*. The term *genius* comes from Latin and means *to beget, bring forth* or to create.

If a person is going to be creative, he or she needs knowledge and skills. For many psychologists, intelligence tests measure a person's ability to acquire knowledge and to use it to solve problems (Sternberg, 1997). Several psychologists have tested the relationship between creativity and intelligence as determined by IQ tests. Some psychologists, such as Torrance (1975), suggested that IQ and creativity are only moderately related. Others, such as Barron and Harrington (1981), found only a weak relationship between creativity and IQ test results. These findings demonstrated that, depending on the domain of creativity, there are minimal thresholds and after that threshold is reached the IQ does not predict creativity. If, however, the threshold IQ is not reached the lower the IQ, the less the creativity. Studies that assessed the IQs of known creative people have provided converging evidence for the postulate that after a threshold is reached there is not a direct relationship between intelligence and creativity. Thus, overall the correlation between IQ and creativity is weak. While some knowledge and problem solving ability is a necessary component of creativity, high intelligence alone is not sufficient.

When taking IQ tests a person must find the correct answer. Finding the correct answers on IQ tests rely on either calling up stored knowledge (e.g., What is the capital of France, or what does the word *impale* mean?) or using convergent reasoning (e.g., How is an apple and an orange the same?). Creativity, however, is very dependent on a process called divergent thinking, or metaphorically termed *thinking out of the box.* For example, intelligence would be knowing that a brick is used to construct buildings, but divergent reasoning might allow a person to use a brick as an abrasive to remove calluses or to break it apart and make chalk. Fortunately, almost all humans are capable of divergent thinking and thus all humans have creative capacity.

Specific knowledge and special talents. Studies of patients with discrete brain lesions suggest that an injury, such as a stroke, to one area of a person's brain can cause different cognitive deficits than a lesion in another part of the brain. For example, an injury to the left lower (ventral) portion of the left temporal-occipital region (see Figure 2) might cause a loss of a person's ability to read, but an injury to the same region on the right side would cause an inability for that person to recognize familiar faces. These types of observations support the hypothesis that the human brain is organized in a modular fashion. More recent studies using electrophysiological techniques and functional brain imaging have supported this concept of modular organization.

Figure 2. Regions of the Left Hemisphere of the Brain



Note. On this side view of the brain's left hemisphere, the numbered areas of the cortex known as Brodmann's areas are shown. Areas 17-19 comprise the occipital lobe, areas 38, 41, 42, 20, 21, 22, and 37 the temporal lobe, areas 1, 2, 3, 7, 39 and 40 the parietal lobe and the remainder 4, 6, 8, 9, 10, 11, 44, 45, 46, and 47 the frontal lobe.

Source: *Tool Module: Broadmann's Cortical Areas* web site, which was funded through the Canadian Institutes of Health Research: Institute of Neurosciences, Mental Health and Addiction. Used within copyleft ©guidelines. Accessed on December 14, 2010 at http://thebrain.mcgill.ca/flash/capsules/outil_jaune05.html

Developmental disorders can also be associated with specific cognitive disabilities. There are multiple reports of children with specific disabilities in reading, math, drawing, music, and route finding. Just as there are people who have specific developmental disabilities, there are also people who have exceptional skills in one or more of these domains. Gardner's (1983) theory of multiple intelligences is built upon this concept. Weisberg (1999) examined the relationship between knowledge and creativity, and concluded from this review that domain specific knowledge is a prerequisite for creativity. For example, an author of fiction must have domain specific knowledge in language skills including a large vocabulary and knowledge of grammar. A visual artist should have the ability to form visual images of the subjects he or she is planning to paint.

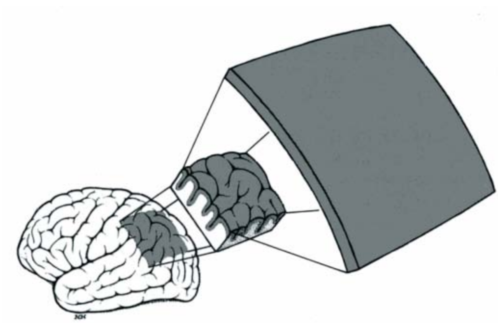
The more nerve cells and connections between these nerve cells a person has in a certain area of the brain, the better this area might be able to carry out a specific function. This hypothesis was first supported by the research of Geschwind and Levitsky (1968) who showed that the area of the brain that stores the memories of how words sound, which is on the left side of the brain, is larger than the same area on the right side of the brain. It has also been shown that talented musicians also have a larger auditory cerebral cortex than do non-musicians. However, the reason people have greater abilities or talents in other domains are not entirely known at this time.

Disability or gift. Many people who have been creative geniuses appeared to have had learning disabilities. For example, there are many great artists, such as Picasso who did not do well in school because of language disabilities. Einstein, as another example, did not learn to speak until the age of three (Hoffman & Dukas, 1972), and later appeared to have dyslexia (Kantha, 1992).

Though Einstein wished to be cremated, he also wanted his brain to be used for research so that people might be able to learn why he was creative. After he died in 1955, Thomas Harvey, the pathologist at a Princeton, New Jersey hospital, removed Einstein's brain so that it could be studied by neuroscientists.[1] Unfortunately, Dr. Harvey sectioned Einstein's brain into hundreds of small blocks and sent it to a variety of people. Fortunately, he did take photographs before cutting Einstein's brain into little pieces. Witelson, Kigar, and Harvey (1999) viewed these pictures of Einstein's brain and found that the major cleft between the temporal lobe and the parietal lobe (see Figure 1), called the Sylvian fissure, was shorter in Einstein's brain than in most people. Normally at the end of the Sylvian fissure, where the temporal lobe ends, there is a branch of this cleft that turns upward. This branch is called the ascending ramus and this ascending ramus divides a part of the inferior parietal lobe, the supramarginal gyrus, into two divisions. Einstein did not have this ascending ramus. Based on these observations, not only did Witelson and her colleagues posit that these anatomic deviations provided Einstein with an enlarged left inferior parietal lobe but also, unlike most people, Einstein's parietal lobe was not divided. The parietal lobe has been shown to be important in many cognitive functions and therefore Witelson and her co-authors suggested that this large and uninterrupted parietal lobe endowed Einstein with an enhanced ability to perform the type of computations needed in physics.

Although Witelson, Kiger, and Harvey’s (1999) hypothesis has not yet been tested, the brain’s sulci (valleys) and fissures are products of human brain growth. Though Einstein did not have an ascending ramus, I suggested that the growth of Einstein’s inferior parietal cortex was not as great as those who do have such a fissure (Heilman, 2005). If the brains of different types of animals are examined and compared, one of the main differences between animals who are more adaptive and more advanced versus those who are less advanced is the size of the cerebral cortex. The size of the cerebral cortex is dependent on two factors, the size of the brain and the number of fissures, gyri, and sulci. The presence of fissures, gyri, and sulci allow more cortex to exist in a fixed volume (see Figure 3).

Figure 3. Pleats (gyri) of Cortex Unfolded (schematic)



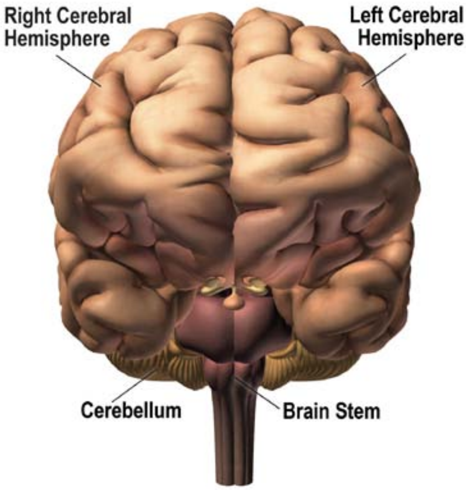
Source: *Nature’s Masterpiece: The Brain and How it Works* by J. L. Pool (1987), p. 11. Copyright 1987 by J. L. Pool, Illustrations Copyright 1987 by N. Hardy. Reprinted with permission of N. Hardy.

About 30 years after Thomas Harvey sent little pieces of Einstein's brain to people around the world, Diamond, Scheibel, Murphy, and Harvey (1985) reported that a piece of the brain they received, which came from Einstein's left parietal lobe, had relatively less neurons than did the control subjects, but relatively more of the supporting cells called glia. Diamond and her coworkers attempted to explain this alteration by suggesting that he might have required more glial cells, because with Einstein's great conceptual powers he had a greater neuronal metabolic need and these glial cells supported this need.

There is, however, another explanation of the findings reported by Witelson et al. (1999) as well as Diamond, et al. (1985). As mentioned, Einstein had developmental language disorders manifested by a delay in speaking as well as developmental dyslexia. Dejerine (1891) demonstrated that lesions of the left parietal lobe can cause an acquired reading disorder (i.e., alexia), and Kantha (1992) suggested that the abnormalities reported by Diamond et al. may have been related to Einstein's dyslexia rather than his genius.

Whereas the left hemisphere is important for language, including speaking, reading, and writing, the right hemisphere appears to be more important for spatial reasoning (see Figure 4, next page) (Benton, Hannay, & Varney, 1975). Einstein stated that his creativity was heavily dependent on spatial reasoning and spatial imagination (Metcalfe & Wiebe, 1987). Geschwind and Galaburda (1985) suggested that the delay in the development of the left hemisphere might have allowed the right hemisphere, which mediates spatial reasoning, to become highly specialized. Perhaps the abnormal development of Einstein's left hemisphere may have allowed his right hemisphere to become highly specialized for spatial computations. Support of this postulate comes from observations of patients who have focal degenerative diseases. For example, Miller, Boone, Cummings, Read, and Mishkin (2000) described several patients who had a disease that causes degeneration of the left frontal and temporal lobes (i.e., frontotemporal lobar degeneration) who developed into wonderful artists. Drawing and painting is very heavily dependent on visuospatial skills and visuospatial imagery. Because these patients have degeneration of the areas of the left hemisphere that mediates speech and language many of these patients have progressive disorders of verbal communication (i.e., primary progressive aphasia). However, according to Miller, Boone, Cummings, Read, and Mishkin (2000), this left hemisphere degeneration led to the facilitation of right hemisphere mediated artistic-visual spatial skills.

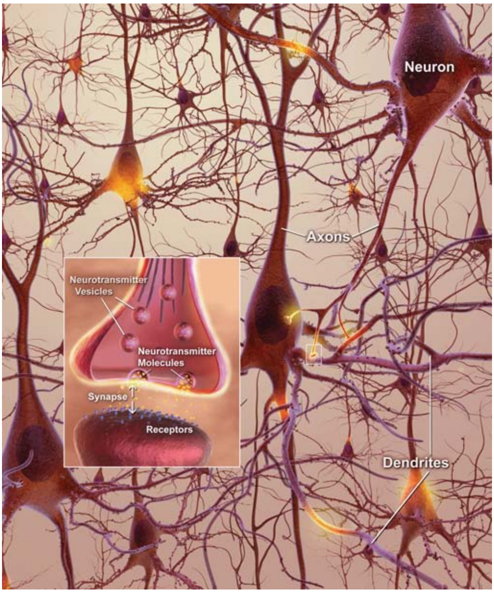
Figure 4. A Frontal View of the Brain Showing the Right and Left Hemispheres, the Cerebellum, and the Brain Stem



Note. Adapted from an image found at the Alzheimer's Disease Education and Referral Center web site originally from the book *Alzheimer's Disease: Unraveling the Mystery* provided through the National Institute on Aging and the National Institute of Health. Used with permission. Accessed on January 10, 2010 at http://www.nia.nih.gov/Alzheimers/Resources/LowRes.htm

Nature or nurture. Nerve cells or neurons (see Figure 5, next page), like trees, contain branches. These branches can be multiple short branches called dendrites or long branches called axons. In the cerebral cortex these branches meet with the branches of many other neurons and these neurons communicate with each other by giving off chemicals that excite or inhibit these adjacent neurons. These meeting places are called synapses. Learning and memories are based on alterations of synaptic strength among neurons in these networks. The more neurons a person has in a particular network, and the greater the branching of the neurons in this network, the more knowledge that this network can store. Thus, a person with high levels of knowledge in a domain might

Figure 5. A View of Neurons with their Axons and Dendrites



Note. The close-up window shows the electro-chemical activity across a synapse. Adapted from an image found at the Alzheimer's Disease Education & Referral Center web site originally from the book *Alzheimer's Disease: Unraveling the Mystery* provided through the National Institute on Aging and the National Institute of Health. Used with permission. Accessed on January 10, 2010 at http://www.nia.nih.gov/Alzheimers/Resources/LowRes.htm

have more neurons, or more connections between these neurons, in the brain region that stores memories in this conceptual domain. Rosenzweig and Bennett (1996) found that rodents put in enriched environments from an early age could learn more rapidly and store more knowledge than the rodents who did not receive this enrichment. These investigators also found the rodents who received this enrichment had a thicker cerebral cortex. The neurons in the cortex had an increase in the number of dendritic spines that are critical for storing knowledge. Many of the world's great geniuses grew up in enriched environments. For example, Mozart's father was also a composer, a director of a symphony, and a music teacher. Beethoven's father was also a music teacher and Chopin’s mother was a music teacher. In contrast to these composers, children put in orphanages, where they received little stimulation, for the most part have very low intelligence and are cognitively disabled (Kaler & Freeman, 1994). Although there is strong evidence that creativity is heavily dependent on nurture, the child still needs the biological capacity (i.e., nature) to benefit from being nurtured. There are many people who have enormous specialized knowledge and even talent who, never the less, are not creative. Thus general intelligence, special knowledge, and talent are necessary but not sufficient for creative innovation (Kraft, 2005).

DISENGAGEMENT AND DIVERGENT THINKING

In the definition of creativity given earlier, I mentioned that creativity requires the *novel* or *new* understanding and expression of orderly relationships. In order to develop new ideas and new products a person must first be able to break away from already accepted ideas, beliefs, and practices. This is called *disengagement.* People and societies typically like and encourage stability and discourage or even abhor dramatic changes. Thus, in many domains disengagement is often discouraged and even scorned. However, disengagement alone does not lead to innovation. After disengaging, the creative person must think and develop ideas that are in a different direction from the prevailing modes of thought and expression. This form of reasoning and development is called *divergent thinking*.

Denny-Brown and Chambers (1958) suggested that all animals, from amoeba to humans have two basic forms of behavior, they either approach or avoid. In humans the frontal lobes mediate avoidance behaviors and the temporal-parietal lobes mediate approach behaviors (see Figure 2). Patients with injury to their frontal lobes will often demonstrate all forms of abnormal approach behaviors, both physical and mental. For example, Lhermitte (1983) placed objects in front of patients with frontal lobe injuries. Without being asked to use these objects the patients would pick up the objects and start using them. Luria (1969) developed some simple tasks to demonstrate that patients with frontal lobe dysfunction are stimulus (i.e., environmentally) dependent and are impaired at disengaging. For example he asked these patients "When I put up one finger you put up two fingers and when I put up two you put up one." He found that although these patients remembered these rules, they could not disengage from the stimulus they saw and when the examiner put up one finger or two fingers they would often initially mimic the examiner and then would attempt to correct their errors. Some patients we see in clinic are so impaired in disengagement that when we ask them to write a series of M and Ns (i.e., mnmnmnmnmn), they will instead write all Ms or all Ns.

In these tasks described by Luria (1969) the patients were given the alternatives, (i.e., when I put up two fingers you put up one . . . .) but were impaired at disengaging. When assessing divergent thinking the person being tested is not given the alternative. Zangwell (1966) suggested that frontal lobe dysfunction could disrupt divergent thinking. Berg (1948) developed the *Wisconsin Card Sorting Test*. The person taking this test is provided with a deck of cards. On these cards are assortments of shaped figures that also have different colors, different sizes, and a different number of these figures on each card. Although the subject is asked to sort these cards according to a dimension, the subject is not informed of the sorting principles (e.g., shape), but must deduce this from the response of the examiner after each sort. Throughout this test the sorting principles change (e.g., from shape to color) and the subjects must switch her or his strategy based on the responses of the examiner. This test is not a sensitive test of disengagement because the examiner is instructing the subject when to disengage. However, it is a test of divergent thinking because the subject must find a new means of sorting. Milner (1984) demonstrated that patients who had frontal lobectomy for the surgical treatment of intractable epilepsy were impaired at this test, suggesting that the frontal lobes might be critical for the ability to perform divergent thinking. Further evidence that the frontal lobes are important for the ability to disengage and shift to new strategies (divergent thinking) comes from studies of regional blood flow (function imaging) that demonstrated when normal people are performing the *Wisconsin Card Sorting Test* they appeared to activate their frontal lobes (Weinberger, Berman, & Zee, 1986).

One of the best tests for divergent thinking is the *Alternative Uses Test* (Guilford, 1967). The person taking this test is asked to provide alternative uses for objects such as a brick. The score a subject receives on this test is based on originality, flexibility, and fluency. For example, stating that the brick can be used to build fireplaces is not very original, but stating that it can be broken apart into smaller pieces and these can be used as chalk, is a more novel-original use. Flexibility is describing uses in different categories (e.g., building and drawing), and fluency is the number of uses provided in a given time. When creative subjects are providing alternative uses of bricks, their frontal lobes showed more activation than those who were less creative (Carlsson, Wendt, & Risberg, 2000).

It is not entirely known why the prefrontal lobes play such an important role in disengagement and divergent thinking. The frontal lobes, however, do have strong connections with the portions of the temporal and parietal lobes that store information (Pandya & Kuypers, 1969). When a person hears a word such as brick, in addition to activating and recognizing the word form, hearing this word activates a semantic network of concepts that are related to the word that is heard. The concepts that are most commonly associated or learned at the earliest age are the ones that are the most strongly connected. These concepts are the ones that are most likely to be activated (e.g., buildings, walkways, fence-wall, fire places). Perhaps the connections from the frontal lobes to these conceptual networks are important for inhibiting the activated networks that store semantically similar information while exciting or activating the semantic conceptual networks that have been only weakly activated or not activated at all. Thus, it is the activation of these more remote networks that may be important in developing the alternative solutions characteristic of divergent thinking.

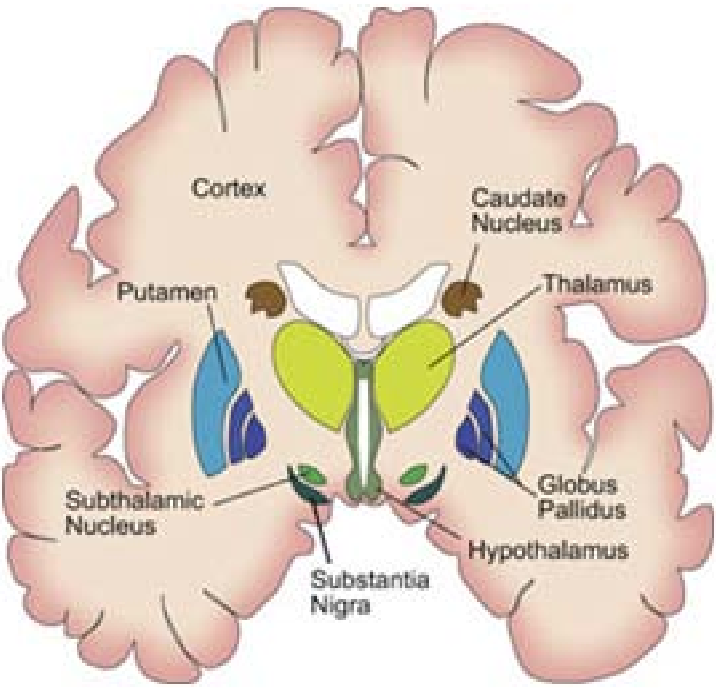
It is unclear if the ability to disengage and develop divergent thought can be nurtured. Heilman and Donda (2007) noted that Albert Einstein said, "It is amazing that our educational system doesn't destroy all curiosity." As we mentioned above, there is evidence that stimulation induces neuronal development and forms of sensory and intellectual deprivation retard development of specific brain areas. While we do not know if our schools destroy all curiosity, current educational programs certainly do not teach, foster, or encourage divergent thinking. Most school's curriculum and testing are directed at the acquisition of knowledge and the use of convergent thought. Thus, it is possible that if children are only taught to acquire knowledge and use convergent reasoning they might not fully develop their frontal lobes.

NOVELTY SEEKING

Highly creative people are often looking for what is new and different and thus are novelty seekers. Many creative people after having a novel-creative thought, or having discovered something new, or produced a creative product, get a feeling of joy and excitement. For example, Tchaikovsky (as quoted in Vernon, 1970) stated "It would be vain to put into words that immeasurable sense of bliss which come[s] over me . . . [when] a new idea awakens in me . . . ." Many drugs can also induce a sense of bliss and many creative people, especially writers, composer-musicians and fine artists, have a very high rate of substance abuse (Post, 1994, 1996). Studies of students who have used drugs versus those who have not used drugs suggest that the former tend to be more creative (Eisenmen, Grossman, & Goldstein, 1980). The reason for the relationship between substance abuse and creativity has not been determined. One hypothesis is that drugs enhance creative performance, but studies of creativity under normal verses intoxicated states do not reveal that drugs enhance creativity (Lang, Verret, & Watt, 1984; Lapp, Collins, & Izzo, 1994). Risk takers and creative people would have to be considered *novelty seekers*, and there is evidence that novelty seekers are at increased risk for drug abuse.

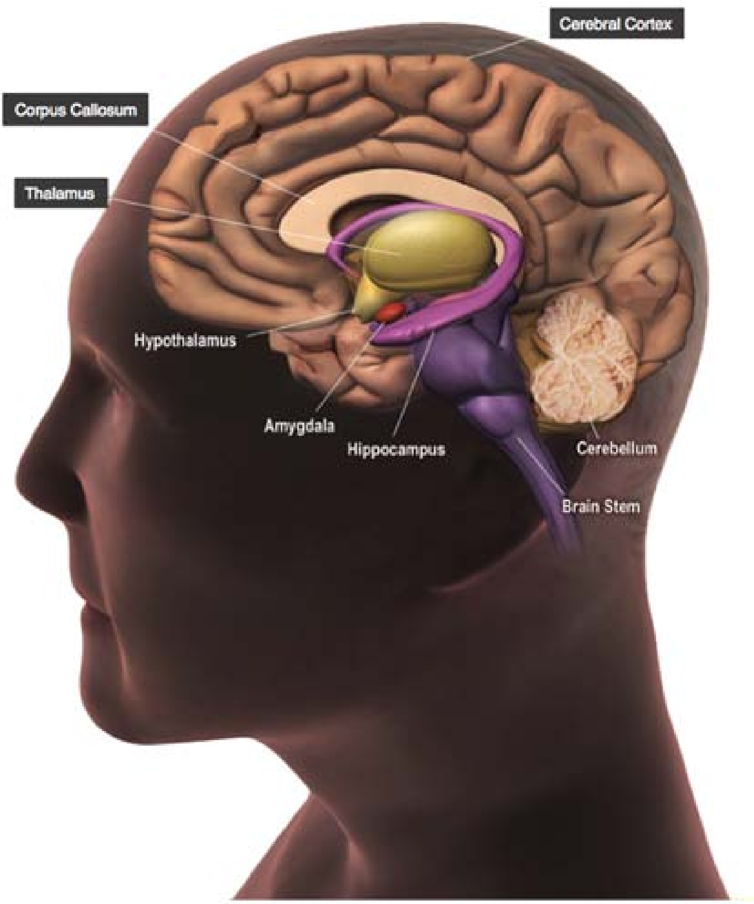
Under the cortex there are groups of neurons that are called the basal ganglia (see Figure 6, next page). Two of the largest basal ganglia nuclei are the putamen and caudate and together they are called the straitum. The straitum is divided into a high or dorsal portion and a low or ventral portion. This ventral striatum is connected to another subcortical group of neurons called the nucleus accumbens. This ventral striatal system is strongly connected to several parts of the brain including areas important for smell and taste, portions of the frontal lobe, and portions of the brain that are important in mediating emotions such as the amygdala (see Figure 7). This system also receives dopamine (a neurotransmitter) from the midbrain. Functional imaging studies suggest that this ventral straital system becomes active during reward. Medications called dopamine agonists, which increase the brain's sensitivity to dopamine, are used to treat patients with Parkinson's disease who have reduced levels of dopamine. One of the complications of this treatment is that many of these patients become high risk takers. There is some evidence that exposure to novelty also activates the mesolimbic dopamine (DA) system of the brain (Bardo, Donohew & Harrington, 1996), and it is this same neural system that mediates the rewarding effects from drugs of abuse. These observations suggest that novelty, discovery, and creativity can excite this reward system just like drugs of abuse.

Figure 6. A View of a Brain, that has been Bisected Horizontally, Showing the Various Structures of the Basal Ganglia



Source: K. Sukel (2007, January 15). Basal ganglia contribute to learning, but also certain disorders. *The Dana Foundation – Brainwork.* Used with permission.
http://www.dana.org/news/Brainwork/detail.aspx?id=6028

Figure 7. Structures in the Core of the Brain



Note. The left hemisphere has been removed for this view. Adapted from an image found at the Alzheimer's Disease Education and Referral Center web site originally from the book *Alzheimer's Disease: Unraveling the Mystery* provided through the National Institute on Aging and the National Institute of Health. Used with permission. http://www.nia.nih.gov/Alzheimers/Resources/LowRes.htm

CONNECTIVITY

In the beginning of this chapter creativity was defined as the ability to understand, develop, and express, in a systematic fashion, novel orderly relationships. As mentioned, studies of patients with discrete lesions of the brain, electrophysiological studies and functional imaging also demonstrate that the brain is organized in modular fashion. The understanding of relationships often requires that the creative person finds *the thread that unites*. Finding the thread that unites sometimes requires seeing the problem in a *new light* and sometimes requires looking at something from a *different perspective*. James (1880) suggested that creativity requires an "unheard of combination of elements and the subtlest associations" (p. 456), and Spearman (1931) suggested that creative ideas result from the combination of two or more ideas that have been previously isolated. Because the right and left hemispheres store different forms of knowledge and mediate different forms of cognitive activity, different neuronal architectures probably exist within the association cortices of each of the hemispheres. A possible method of resolving a previously unsolved problem is to see this problem *in a new light.* A means of seeing a problem in a new light is to use the different forms of knowledge and cognitive strategies mediated by the opposite hemisphere. Thus, the understanding, development, and expression of orderly relationships most often require communication between these modules.

The strongest evidence for modularity is hemispheric specialization with the left hemisphere being important for proposition language including speech, reading, and writing. However, some parts of speech and language are also mediated by the right hemisphere including emotional prosody and metaphor. For example, when a patient with a right hemispheric stroke hears that a person has a heavy heart, they might interpret that as meaning that the person has enlargement of their heart (Brownell, Simpson, Bihrle, Potter, & Gardner, 1990). Thus, the creative playwright often will use metaphor and emotional prosody mediated by the right hemisphere, along with propositional language mediated by the left hemisphere. The novelist who is writing about an emotional response of a character must use the knowledge of facial emotional expressions stored in the right hemisphere together with the verbal lexicon stored in the left hemisphere. The left hemisphere mediates mathematical calculations, but the right hemisphere appears to be important in spatial cognition (Benton, Hannay, & Varney, 1975), including spatial imagery (Butters, Barton, & Brody, 1970). Thus, physicists must also use both hemispheres when developing new theories. The programming of skilled movements is mediated by the left hemisphere (Liepmann, 1920), but the right hemisphere mediates spatial relationships. Thus, the sculptor must also use both hemispheres. When creating a painting the artist has to focus on specific objects in the painting as well as coordinating the relationships of these objects with the background. Whereas the left hemisphere mediates categorical thinking and focused attention, the right mediates continuous-coordinate thinking and global attention (Barrett, Beversdorf, Crucian, & Heilman, 1998; Robertson, Lamb, & Knight, 1988; and Kosslyn, 1998). These are but a few examples of the inter-hemispheric communication important in creativity. In almost every creative act the creative person uses the skills and knowledge mediated by both hemispheres.

The structure connecting independent modular systems in the right and left hemisphere is the corpus callosum (see Figure 7). Springer and Deutsch (1989) recounted the history of a surgical procedure known as a split-brain operation, or commissurotomy. In this type of operation patients who had seizures that could not be controlled with medicines had their corpus callosum cut so that the seizure would not spread from one hemisphere to the other. Lewis (1979) administered the *Inkblot* or *Rorschach* test, which has been used to assess creativity, to eight patients who had undergone a cerebral commissurotomy. The test was administered both before and after they had this surgery. Lewis noted that disconnection of the two cerebral hemispheres tended to destroy creativity as measured by this test. Bogen and Bogen (1988) posited that although the corpus callosum transfers information between the hemispheres, hemispheric specialization still occurs. They further suggested that because this inter-hemispheric communication is normally incomplete, this incompleteness permits hemispheric independence and specialization. The Bogens also suggested that it is the momentary suspension of this partial independence that accounts for creative innovation. A recent study by Moore, et al. (2009), who studied creativity and the size of the corpus callosum supported Bogen and Bogen's theory. Moore, et al.'s study found that people who have more creativity had smaller callosums than those with less creativity. Neither the Bogens nor Moore, et al., however, stated what accounts for the temporary suspension of this partial hemispheric independence that is critical for creative innovation.

Mednick (1962) noted that when generating associative responses to a stimulus, creative individuals are characterized by a flatter associative hierarchy than are less creative individuals. This suggested to Mednick that creative people have the ability to activate highly distributed semantic-conceptual networks. In other words they are able to cast a larger conceptual net and activate even remote associations. Even intra-hemispherically, the frontal lobes might be involved in the discretionary-intentional activation of selected units in a network. This phenomenon provides creative people a means of asking, *What if* questions and thereby producing novel patterns of activation corresponding to novel concepts.

Support for Mednick's (1962) theory came from electroencephalographic (EEG) studies of normal subjects, who during creative thought, demonstrated an increase of anatomically distributed coherence of EEG oscillations (Petsche, 1996; Jausovec & Jausovec, 2000). The mechanism by which the size of brain networks are modulated and co-activated is unknown, but in the next section several possible mechanisms will be discussed.

MODULATING BRAIN NETWORKS: SLEEP AND RELAXATION

Many creative people have noted that they developed insight into a difficult problem or had creative thoughts when they were either falling asleep or were awakening from sleep. Although there is a lot of debate about the veracity of this story, one of the best known examples of the relation between sleep and creativity is the story of August Kekule. In 1865 the structure of one of the most important organic chemicals, benzene, was unknown. During sleep or while in a sleepy state Kekule dreamed of a snake chasing its tail and this dream provided Kekule with the idea that benzene is in a ring-like structure (Barrett, 2001). When writing about mathematical geniuses, Dehaene (1997) noted that many claimed that some of their most creative moments occurred during sleep.

In 1897, Ramón y Cajal (As translated by N. Swanson and L. Swanson, 1999), the founder of the nerve theory, wrote a book entitled *Advice for a Young Investigator*, where he suggested,

> If a solution fails to appear after all of this, and yet we feel success is just around the corner, try resting for a while. Several weeks of relaxation and quiet in the countryside brings calmness and clarity of the mind. Like the early morning frost, this intellectual refreshment withers the parasitic and nasty vegetation that smothers

> the good seed. Bursting forth at last is the flower of truth, whose calyx usually opens after a long and profound sleep at dawn-in those placid hours of the morning that Goethe and so many others consider especially favorable for discovery. (p. 35)

Kuhn (1996) described a revolution in scientific thinking as a *paradigmatic shift*. Some of the greatest paradigmatic shifts in the modern era were Darwin's theory of evolution, Einstein’s theory of relativity, Newton’s development of calculus, and Mendel’s hereditary theory, which led to the science of genetics. Darwin developed his theory of evolution while cruising on the Beagle. Einstein did much of his work late at night in a patent office. Cambridge University was closed because of the bubonic plague when Newton went to his mother’s farm and while relaxing developed calculus. Mendel was gardening sweet peas when he developed the hereditary-genetic theory. All these paradigmatic shifts occurred during the times these creative people were resting or relaxing.

The reason why sleep and relaxation might lead to creative innovation is not entirely known, but Easterbrook (1959) suggested that high cortical arousal induced by stress might suppress the emergence of remote associations, and a lower degree of cortical arousal might allow unusual associations to become manifest. As discussed previously, the activation of remote association is an important aspect of innovation. One of the neurotransmitters that help to modulate the brain’s arousal is norepinephrine. Thus, the thread that unites sleeping-dreaming, resting and relaxing is changes in the level of the neurotransmitter norepinephrine (McCarley, 1982).

Stress is associated with high levels of norepinephrine and relaxation with low levels. Many mental diseases have been associated with alterations of neurotransmitters. For example, it is thought that in depression there is a reduction of norepinephrine and people with a history of depression often are very creative (Post, 1994; Post, 1996).

Support for the postulate that certain neurotransmitters, such as norepinephrine, modulate the size of neuronal networks comes from several studies. One such study used a word priming task where the subjects were told that on the screen in front of them they would see a series of letters. These letters might spell a real word or a pseudo-word. If they saw a word they were to press the computer key as rapidly as possible. They were also told that sometime before the target word or non-word came on the screen they would see another word that might or might not be related to the target word. This word is called the *prime*. If prime is the word *tiger* and the target is *lion* a person will press the key more rapidly when he or she sees the word *lion* than if there were no prime or an unrelated prime. If the prime word was weakly related (e.g., stripes) then this prime would slightly reduce the reaction time when compared to no prime or an unrelated prime. Kischka, Kammer, Maier, Weisbrod, Thimm, and Spitzer (1996) used this type of lexical priming with normal participants. When they administered levodopa (a medication used to treat Parkinson's disease) they found that direct semantic priming (e.g., tiger-lion) was only marginally influenced, but indirect priming was no longer present (e.g., stripes-lion). These results suggested to Kischka, et al. (1996) that increasing the brain's dopamine reduced the breadth of the semantic network activated by the prime. However, the administration of levodopa also increases the level of brain norepinephrine.

In the *Remote Associates Test*, subjects are presented with a series of trials in which they are given three words (e.g., American, blue, and goat) and are requested to find a word that is associated with all three words (e.g., cheese). Like the priming task discussed earlier, this test might assess the size-breadth of lexical-semantic networks. If subjects are put under stress conditions when taking this test (e.g., state anxiety), their performance deteriorates (Martindale and Greenough, 1973). Stress increases the activity of the noradrenergic system, which is the system of neurons that create, store, and release norepinephrine into the brain.

In medical terms, norepinephrine also changes the brain's signal-to-noise-ratio by suppressing intrinsic excitatory synaptic potentials relative to the potentials elicited by direct, external afferent input (Hasselmo, Linster, Patil, Ma, & Cekic, 1997). In other words, norepinephrine would be the cause of why, in a classroom full of noisy, active students, a technology education teacher's attention is suddenly focused laser like on the one student who is using a tool or machine in a way that could cause physical injury to themselves or others. This norepinephrine-based bias toward external stimuli might be important for *flight or fight* activities. However, this brain state might interfere with self-reflection as well as activating and manipulating the widespread network that is so important in creativity.

When students are very anxious they perform poorly on tests such as the *Scholastic Aptitude Test* (SAT), but when these students take a medication that blocks norepinephrine in the brain (e.g., propranolol) their scores improve (Faigel, 1991). This blocking drug might help because with reduced brain norepinephrine they can enlarge their semantic networks as well as increase their cognitive flexibility.

To directly test the hypothesis that norepinephrine modulates cognitive flexibility, which allows a person to see the thread that unites, Beversdorf, Hughes, Steinberg, Lewis, and Heilman (1999) tested normal participants' abilities to solve anagrams when treated with ephedrine or propranolol. Their study found that participants performed better when they had taken propanolol, a blocker of brain norepinephrine.

The vagus nerve carries information from the body's internal organs to the brain, including the locus ceruleus, which is located in the brain stem (see Figures 4 & 7). The locus ceruleus is responsible for reacting to stress and fear and produces the brain's norepinephrine. In our laboratory (Ghacibeh, Shenker, Shenal, Uthman, & Heilman, 2006) we measured peoples' creativity before, during, and after stimulating this nerve. Although the participants did not know when they were being stimulated, we found that stimulation reduced the participant's creative abilities.

As mentioned previously, people appeared to be more creative when they were relaxed than during times when they were stressed. Normally, when a person is awake but relaxed, an electroencephalogram (EEG) will measure 8-12 cycle per second of alpha brain wave activity. With stress and high arousal this alpha activity abates. Martindale and Hasenfus (1978) used the EEG to study creativity based on their participant's ability to write creative stories. These investigators placed subjects into either the creative or uncreative groups and recorded their EEG while resting and when writing stories. They found that in the resting state there were no differences in the EEGs of these two groups, but during the time they were developing their stories (i.e., innovation stage) the creative subjects demonstrated better developed alpha activity than did the uncreative subjects. These results suggest that maintaining a low level of arousal enhances creative innovation.

CONCLUSION

Humans have been trying to understand the brain and its functions for a very long time. The field of neuroscience discovers everyday, through the use of such tools as the electroencephalogram and functional imaging technologies, new insights into the wonders of how the brain provides humankind with a ceaseless stream of creative actions. These insights include a better understanding of how the typical brain is organized and functions, and how both nature and nurture can have profound effects on its development. The brain of a healthy human is biologically equipped for creative activity, whether it be found in the potential of the dense forest of neural connections in the cerebral cortex, or in the different ways in which the right and left hemispheres process knowledge or form cognitive strategies, or in the uniquely human way that the frontal lobes engage in divergent thinking. Properly nurturing these biological building blocks of creativity can enhance their capacities for creative activity. Educators at all levels should learn from these discoveries so that they may use this knowledge to positively affect the growth and development of their student's intellect and creative capabilities.

REFLECTIVE QUESTIONS

1. What are the three stages of creativity and how would you apply them to a technology and engineering activity in your classroom?
2. How do an individual's knowledge, intelligence, and special skills contribute toward his or her creativity?
3. From small structures such as the neurons to larger structures such as the cerebral cortex nature has provided humans with the biological building blocks of creativity. How can teachers help to nurture those building blocks in their students?
4. What are the differences in how the right and left hemispheres of the brain process input/stimuli from the environment and how does each hemisphere contribute toward an individual's creativity?
5. Stress tends to suppress creativity. Why does this occur and what can a teacher do to minimize the influence of stress in his or her classroom?

FOOTNOTE

[1]For a fascinating audio file on the odyssey of Einstein's brain with Dr. Harvey, go to http://www.npr.org/templates/story/story.php?storyId=126229305

REFERENCES

Bardo, M. T., Donohew, R. L., & Harrington, N. G. (1996). Psychobiology of novelty seeking and drug seeking behavior. *Behavioral Brain Research, 77*(1-2), 23-43.

Barrett, A. M., Beversdorf, D. Q., Crucian, G. P., & Heilman, K. M. (1998). Neglect after right hemisphere stroke: A smaller floodlight for distributed attention. *Neurology, 51*, 972-978.

Barrett, D. (2001). *The committee of sleep: How artists, scientists, and athletes use dreams for creative problem-solving — and how you can too*. New York: Crown.

Barron, F., & Harrington, D. M. (1981). Creativity, intelligence and personality. *Annual Review of Psychology, 32*, 439-476.

Benton, A., Hannay, H. J., & Varney, N. R. (1975). Visualperception of line direction in patients with unilateral brain disease. *Neurology, 10,* 907-910.

Berg, E. A. (1948). A simple objective technique for measuring flexibility in thinking. *Journal of General Psychology, 39,* 15-22.

Beversdorf, D. Q., Hughes, J. D., Steinberg, B. A., Lewis, L. D., & Heilman, K. M. (1999). Noradrenergic modulation of cognitive flexibility in problem solving. *Neuroreport, 10*(13), 2763-2767.

Bogen, J. E. & Bogen, G. M. (1988). Creativity and the corpus callosum. *The Psychiatric Clinics of North America, 11*, 293-301.

Bronowski, J. (1972). *Science and human values*. New York: Harper and Row.

Brownell, H. H., Simpson, T. L., Bihrle, A. M., Potter, H. H., & Gardner, H. (1990). Appreciation of metaphoric alternative word meanings by left and right brain-damaged patients. *Neuropsychologia, 28*(4), 375-383.

Butters, N., Barton, M., & Brody, B. A. (1970). Role of the right parietal lobe in mediation of cross-modal associations and reversible operations in space. *Cortex, 6,* 174-190.

Carlsson, I., Wendt, P. E., & Risberg, J. (2000). On the neurobiology of creativity: Differences in frontal activity between high and low creative subjects. *Neuropsychologia, 38,* 873-885.

Dehaene, S. (1997). *The number sense*. New York: Oxford University Press.

Dejerine, J. J. (1891). Sur un cas de cecite verbal avec agraphie suivi d'autopsi. *Mèmores de la Societè de Medicine, 3,* 197-201.

Denny-Brown, D., & Chambers, R. A. (1958). The parietal lobe and behavior. *Research Publications: Associations for Research in Nervous and Mental Disease, 36,* 35-117.

Diamond, M. C., Scheibel, A. B., Murphy, Jr., G. M., & Harvey, T. (1985). On the brain of a scientist: Albert Einstein. *Experimental Neurology,* 198-204.

Easterbrook, J. A. (1959). The effect of emotion as one utilization and the organization of behavior. *Psychological Review, 66,* 183-201.

Eisenman, R., Grossman, J. C., & Goldstein R. (1980). Undergaduate marijuana use as related to internal sensation novelty seeking and openness to experience. *Journal of Clinical Psychology, 36*(4), 1013-1019.

Eysenck, H. J. (1995). *Genius: The natural history of creativity*. New York: Cambridge University Press.

Faigel, H. C., (1991). The effects of beta blockade on stress-induced cognitive dysfunction in adolescents. *Clinical Pediatrics, 30,* 446-448.

Florida, R. (2002). *The rise of the creative class*. New York: Basic Books.

Gardner, H. (1983). *Frames of mind.* New York: Basic Books.

Geschwind, N. & Galaburda, A. M. (1985). Cerebral lateralization. Biological mechanisms, associations and pathology: A hypothesis and program for research. *Archives of Neurology, 42,* 428-459 and 634-659.

Geschwind, N., & Levitsky, W. (1968). Human brain: Left-right asymmetries in temporal speech region. *Science, 161,* 186-187.

Ghacibeh, G. A., Shenker, J. I., Shenal, B., Uthman, B. M., & Heilman, K. M. (2006). Effect of vagus nerve stimulation on creativity and cognitive flexibility. *Epilepsy & Behavior, 8*(4), 720-725.

Hasselmo, M. E., Linster, C., Patil, M., Ma, D., & Cekic, M. (1997). Noradrenergic suppression of synaptic transmission may influence cortical signal to noise ratio. *Journal of Neurophysiology, 77,* 3326-3339.

Heilman, K. M., & Donda, R. S. (2007, Sept.-Oct.). Neuroscience and fundamentalism. *Tikkun, 22*(5), 54-60.

Heilman, K. M. (2005). *Creativity and the brain.* New York: Psychology Press, Taylor & Francis Group.

Heilman, K. M., Nadeau, S. E., & Beversdorf, D. O. (2003, October). Creative innovation: Possible brain mechanisms. *Neurocase, 9*(5), 369-379.

Hoffman, B., & Dukas, H. (1972). *Albert Einstein: Creator and rebel*. New York: Viking Press.

James, W. (1880). Great men, great thoughts, and the environment. *Atlantic Monthly, 46,* 441-459.

Jausovec, N. & Jausovec, K. (2000). Differences in resting EEG related to ability. *Brain- Topograpy, 12,* 229-240.

Kaler, S. R. & Freeman, B. J. (1994) Analysis of environmental deprivation: cognitive and social development in Romanian orphans. *Journal of Child Psychology and Psychiatry, 35*(4), 769-781.

Kantha, S. S. (1992). Albert Einstein's dyslexia and the significance of Brodmann Area 39 of his left cerebral cortex. *Medical Hypotheses, 37,* 119-122.

Kischka, U., Kammer, T., Maier, S., Weisbrod, M., Thimm, M., & Spitzer, M. (1996). Dopaminergic modulation of semantic network activation. *Neuropsychologia, 34,* 1107- 1113.

Kosslyn, S. M. (1998). Neural systems that encode categorical versus coordinate spatial relations: PET investigations. *Psychobiology, 26,* 333 347.

Kraft, U. (2005). Unleasing creativity. *Scientific American Mind, 16*(1), 16-23.

Kuhn, T. S. (1996). *The structure of scientific revolutions* (3rd ed.). Chicago: University of Chicago Press.

Lang A. R., Verret, L. D., & Watt, C. (1984). Drinking and creativity: Objective and subjective effects. *Addictive Behavior, 9*(4), 395 399.

Lapp, W. M., Collins, R. L., & Izzo, C. V. (1994). On the enhancement of creativity by alcohol: Pharmacology or expectation? *American Journal of Psychology, 107*(2), 173 206.

Lewis, R. T., (1979). Organic signs, creativity, and personality characteristics of patients following cerebral commissurotomy. *Clinical Neuropsychology, 1,* 29-33.

Lhermitte, F. (1983). 'Utilization behaviour' and its relation to lesions of the frontal lobes (Part II). *Brain, 106,* 237-255.

Liepmann, H. (1920). Apraxia. *Ergebnisse der Gesamten Medizin, 1,* 516–543.

Luria, A. R. (1969). Frontal lobe syndrome. In P. J. Vinkin and G. W. Bruyn (Eds.), *Handbook of Clinical Neurology (Vol. 2*). Amsterdam: North Holland Publishing.

Martindale, C. & Greenough, J. (1973). The differential effect of increased arousal on creative and intellectual performance. *Journal of Genetic Psychology, 123,* 329-335.

Martindale, C. & Hasenfus, N. (1978). EEG differences as a function of creativity, stage of creative process, and effort to be original. *Biological Psychiatry, 6,* 157-167.

McCarley, R. W. (1982). REM sleep and depression: Common neurobiological control mechanisms. *American Journal of Psychiatry, 139,* 565-570.

Mednick S. A. (1962). The associative basis of the creative process. *Psychological Review, 69,* 220-232.

Metcalfe, J. & Wiebe, D. (1987). Intuition in insight and noninsight problem solving. *Memory Cognition, 15,* 238-246.

Miller, B. L., Boone, K., Cummings, J. L., Read, S. L., & Mishkin, F. (2000). Functional correlates of musical and visual ability in frontotemporal dementia. *British Journal of Psychiatry, 176,* 458-463.

Milner, B. (1984). Behavioural effects of frontal-lobe lesions in man. *Trends in Neurosciences, 7,* 403-407.

Moore, D. W., Bhadelia, R. A., Billings, R. L., Fulwiler, C., Heilman, K. M., Rood, K. M., & Gansler, D. A. (2009). Hemispheric connectivity and the visual-spatial divergent-thinking component of creativity. *Brain and Cognition, 70*(3), 267-272.

Pandya, D. N. & Kuypers, H. G. (1969, March). Cortico cortical connections in the rhesus monkey. *Brain Research, 13*(1), 13-36.

Petsche, H. (1996). Approaches to verbal, visual and musical creativity by EEG coherence analysis. *International Journal of Psychophysiology, 24,* 145-159.

Pickett, J. P. (Ed.). (2006). *The American Heritage dictionary of the English language* (4th ed.). Boston: Houghton Mifflin.

Post, F. (1994). Creativity and psychopathology: A study of 291 world famous men. *British Journal of Psychiatry, 165*(2), 22-34.

Post, F., (1996). Verbal creativity, depression and alcoholism: An investigation of 100 American and British writers. *British Journal of Psychiatry, 169*(3), 545-555.

Robertson, L. C., Lamb, M. R., & Knight, R. T. (1988). Effects of lesions of temporal-parietal junction on perceptual and attentional processing in humans. *Journal of Neuroscience, 8,* 3757 3769.

Rosenzweig, M. R., & Bennett, E. L**.** (1996, June). Psychobiology of plasticity: Effects of training and experience on brain and behavior. *Behavioral Brain Research, 78*(1), 57-65.

Spearman, C. (1931). *Creative mind*. London: Macmillan.

Sternberg, R. J. (1997). The concept of intelligence and its role in life long learning and success. *American Psychologist, 52,* 1030-1037.

Springer, S. & Deutsch, G. (1989). *Left brain, right brain* (3rd ed.). New York: W. H. Freeman.

Swanson, N. & Swanson, L. W. (1999). *Advice for a young investigator*. (English translation of S. Ramón y Cajal, 1897). Cambridge, MA: MIT Press.

Torrance, E. P. (1975). Creativity research in education: Still alive. In I.A. Taylor and J.W. Getzels (Eds.), *Perspectives in creativity* (pp. 278-296). Chicago: Aldine.

Verfaellie, M., Croce, P., & Milberg, W. P. (1995). The role of episodic memory in semantic learning: An examination of vocabulary acquisition in a patient with amnesia due to encephalitis. *Neurocase, 1*(4), 291-304.

Vernon, P. E. (Ed.). (1970). *Creativity*. Middlesex, England: Penguin.

Wallas, G. (1926). *The art of thought.* New York: Harcourt Brace.

Weinberger, D. R., Berman, K. F., & Zee, R. F. (1986). Physiologic dysfunction of dorsolateral prefontal cortex in schizophrenia. *Archives of General Psychiatry, 43,* 114-124.

Weisberg, R. W. (1999). Creativity and knowledge: A challenge to theories. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 226-250). New York: Cambridge University Press.

Witelson, S. F., Kigar, D. L., & Harvey, T. (1999). The exceptional brain of Albert Einstein. *Lancet, 353,* 2149-2153.

Zangwell, O. L. (1966). Psychological deficits associated with frontal lobe lesions. *International Journal of Neurology, 5,* 395-402.

Creativity, Innovation, and Design Thinking

Chapter 6

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The meanings of words often shift as certain ideas gain traction in popular culture. Through overuse or misuse, some words lose their power to communicate something quite specific and come to stand for a broad array of meanings that may even include the opposite of the original concept.

Such is the case with *creativity*, *innovation*, and the more recently fashionable *design thinking*. The teenager who fills in the pre-printed drawing on needlepoint canvas is praised for being creative. The car company that re-styles the exterior shell of its SUV without changing the energy-consumptive engineering boasts of innovation. Cindy Crawford's experience as a supermodel apparently qualifies her as a furniture designer, the local beauty salon practices hair design, and we covet designer clothes, as if apparel without a famous name springs readymade from nature. *BusinessWeek* columnist Bruce Nussbaum also suggests that design thinking, now deemed essential to entrepreneurial success, may best be left to people with MBAs.

What such examples illustrate is that there is little cultural consensus about what these once-powerful terms really mean. Arguably, these common interpretations actually distance the terms *creativity*, *innovation*, and *design thinking* from the very particular kinds of thinking for which they once stood. Instead, such popular definitions focus our attention on the physical attributes of products (i.e., on the aspects of objects that are whimsical, humorous, seductive, and eccentric) and the general idea of *novelty*. While we can agree that some of these diffused meanings hover around concepts and behaviors that are essential to living a productive life in the twenty-first century, their very ambiguity makes it difficult to determine which teaching and learning strategies will truly support students' creative abilities.

Popular assumptions about creativity also jeopardize students' early success in college design programs (i.e., in the professional study of architecture, graphic design, industrial design, and interior design). Encouraged in high school art classes by perceptions that design is about spontaneous, eccentric solutions, beginning college students often resist the hard work of analysis and synthesis that characterizes much of design problem solving. The evaluative criteria of appropriateness, usability, usefulness, viability, and sustainability often get lost in a quest for the curious, personal, or dramatically different.

So, before curriculum, pedagogy, and assessment that foster students' creative thinking, specifically in relation to design problem solving, I will establish some operational understanding of these concepts.

DISTINGUISHING CREATIVITY FROM OTHER TYPES OF THINKING AND ACTION

Psychologist Csikszentmihalyi (1996) provided a useful definition for creativity. He asserted that the creative person is someone who changes some aspect of a culture, as opposed to someone who simply expresses unusual thoughts or experiences the world in a novel way. He further qualified the concept by saying that creativity never exists only in the mind of a person and that creativity needs the following to function systemically and to have an effect on its surroundings.

- A *domain*: Set of symbolic rules and procedures that are shared within a culture (e.g., mathematics and art are domains);
- A *field*: People who decide whether a new idea should be included in the domain (i.e., teachers, critics, administrators of agencies, publishers, curators, etc.); and
- An *individual*: User of the symbols of a domain to express a new idea or to identify a pattern.

The truly creative person, therefore, is someone whose thoughts and actions change or establish a domain with the explicit consent of the field. Csikszentmihalyi's (1996) definition is useful in its exclusion of activity that is simply novelty-for-novelty's-sake or that is accountable only to personal criteria. While it is unreasonable to expect that young students can make such global contributions, it is important that their creative development be framed in terms that can eventually lead to such outcomes and that expectations be set high. Csikszentmihalyi's definition sets a goal for education to nurture in students those dispositions, skills, and thinking behaviors that are likely to contribute cultural value, while implying there are social standards for judging the quality of creative thought.

Csikszentmihalyi (1996) also described traditional notions of the creative process as involving five mental steps:

- *Preparation* in a set of issues that arouse curiosity and that come from personal experience, requirements of the domain, and social pressures as presented or discovered problems;
- *Incubation* that occurs during a period of time in which ideas percolate seemingly irrelevant associations below the level of consciousness, but according to patterns established by the thinker's knowledge of the domain;
- *Insight* in which one of these associations fits the problem so well that it springs to conscious awareness;
- *Evaluation* through which the thinker decides whether the insight is valuable and worth pursuing (i.e., we monitor developing work, pay attention to goals and feelings, compare ideas to domain knowledge and methods, and interact with others involved in the solution of similar problems); and
- *Elaboration* when the thinker develops convincing modes of presentation that communicate ideas to others.

The creative process rarely unfolds as an unbroken, linear progression of steps. Csikszentmihalyi's articulation of these distinct cognitive behaviors within the creative process, however, suggests that pedagogy and the conditions of the classroom environment can be crucial to creative thinking. The structure of projects should allow time for reflection, as well as production. Creativity extends well beyond the physical attributes of products and includes distinct ways of thinking.

Psychologist Sternberg (1999) reinforced the notion that novelty alone is insufficient in describing creative thinking and cited as obstacles to more substantive criteria those definitions that "render the phenomenon either elusive or trivial" (p. 4). He also argued that judgments about appropriateness or usefulness and the ability to be adaptive concerning task constraints are essential.

The importance of appropriateness was supported by Schwartz's (1987) critique of creativity tests and classroom activities, such as those materials based on the work of E. Paul Torrance,[1] that often separated creativity into primary, "non-judgmental" skills: fluency of thought (i.e., generating many ideas), originality of thought (i.e., generating new ideas), and elaboration of one's thinking. Schwartz also made the case that the development of good thinking skills depends on developing a sense of where they can be used most appropriately and on critical thinking, as well as fluent, original, and detailed thinking.

Sternberg (1996) offered an "investment theory" of creativity in which creative people "buy low and sell high" (p. 10), taking on ideas that are unknown or unpopular in the face of resistance, then moving on to something else when their ideas gain acceptance and application. He suggested that creativity could be predicted by a confluence of resources, including particular intellectual abilities, knowledge, motivation, and environment. Essential to such predication are the synthetic ability to see problems in new ways, the analytical ability to recognize which ideas are worth pursuing, and the practical-contextual ability to persuade others on the value of new ideas. Too much of one ability, and not enough of the others, often results in ideas that are not subjected to rigorous evaluation–critical but not creative–and accepted without merit, simply because they have been "sold" well.

DESIGN THINKING AND INNOVATION

Design thinking and *innovation* are the most recent buzzwords in business that underpin efforts to separate the work of designers–particularly the development of products and services–from more general notions of creativity. References to design thinking and innovation may be found in the writing of management gurus such as Tom Peters (2003), IDEO partner Tom Kelley (2005), and *BusinessWeek* columnist Bruce Nussbaum. Former White House speechwriter Daniel Pink (2005) flirted with a similar concept when he described workplace shifts from left to right brain competencies. And, design thinking routinely appears as a topic in the *Harvard Business Review*, *Fast Company*, and the *Wall Street Journal*.

Strategy firms, such as the Doblin Group in Chicago and IDEO in offices around the world, sell innovation as their product. A 1999 videotape of the IDEO design team redesigning a supermarket shopping cart on *ABC's Nightline* (titled *The Deep Dive*) is the most frequently requested video in the show's history, not because of the cart but because of the company's innovation strategy and flat hierarchy of problem solvers. IDEO founder David Kelley extended the firm's innovation model to Stanford University where he has headed the *d-school*, a program focused on bringing innovation to all aspects of the university's curricula and research.

While, on the surface, all of this public attention and diversification of design practice bolsters the case for design in K-12 education, it also confuses non-designers about what the terms *design thinking* and *innovation* really mean. If design thinking is something that can be done equally well by people with backgrounds in business and professionals in design and engineering, then what are the core competencies and ways of thinking that should be the target of student work in design and technology classes? And, what are the characteristics of thinking that are truly innovative and not just procedural or managerial?

The term *design thinking* entered the popular lexicon in the 1970s, under work by British researchers, such as Nigel Cross and Bryan Lawson. Their insights about the design process also shaped attitudes in education.

Cross (2006) argued that design is a third discipline, positioned somewhere between the humanities and the sciences, and should be a part of everyone's general education. He described design expertise as comprising the abilities of

- resolving ill-defined problems,
- adopting solution-focused cognitive strategies,
- employing the logic of conjecture, and
- using nonverbal modeling media (p. 38).

Citing a 1979 study by Thomas and Carroll, Cross (2006) assigned the unique qualities of design thinking to the approach taken to solving a problem, not to the problem itself. Like Csikszentmihalyi's (1996) concept of creativity, this definition is specific enough to guide teachers in structuring student experiences. If design thinking is about inventing strategies for tackling uncertain, ambiguous problems, then assignments that present students with neatly-defined parameters, overly-prescriptive processes, and predetermined outcomes are less likely to incite the desired innovation than challenges in which students bear some responsibility for framing the problem themselves. If design thinking is about making judgments or seeking relationships on the basis of incomplete information, then teachers cannot know the outcome of an assignment (i.e., what the work product will look like) before students begin.

Consistent with analyses of the creative process, Cross's (2006) description of design thinking included *the creative leap*: the sudden act of insight or new perspective on a situation. Rosenman and Gero (1993) offered five procedures through which such leaps may occur:

- *Combination* has the designer bringing together ideas from existing sources into a new configuration.
- *Mutation* involves altering the features of something.
- *Analogy* uses metaphor to describe a concept.
- *First principles* identify concepts that are at the heart of the problem (e.g., a chair must support human weight and certain kinds of posture, a cup must contain liquid, and accommodate the human hand).
- *Emergence* denotes new properties or affordances residing within an existing design.

It is important to understand that such procedures do not happen in a vacuum (e.g., sitting and waiting for the lightning bolt to come through the ceiling is unlikely to be a productive approach). If these procedures are characteristic of design thinking, then it is reasonable to assume that engaging students in such specific challenges will foster the development of creative competencies. For example, an assignment that asks students to construct a paper bridge that will support a brick, or to package an egg for a drop of 20 feet using only toothpicks and glue (It can be done with as few as 16 toothpicks, arranged as a geodesic sphere.), foregrounds the first principle of triangulation as supporting weight, regardless of the material and other formal considerations. It is through the constraint of seemingly weak materials that this first principle is discovered. Were more obviously durable materials an option, students would use them and miss the lesson in triangulation.

Yet another assignment might ask students to design a vehicle using the locomotion of an insect or reptile as an analogy for movement. Or, students might be asked to think about a website interface as operating through some behavior other than point-and-click as a means for finding *emergent properties* or *affordances* in a well-known technology (e.g., see www.dontclick.it). In other words, problem constraints actually encourage the creative leap by directing student attention to certain kinds of thinking procedures–not to solutions–and by deliberately eliminating conventional or predictable options.

Harvard professor Perkins (1986) extended the design process to the search for understanding any kind of knowledge. He used four design questions as a framework for prying open any concept:

- What is its purpose or purposes?
- What is its structure?
- What are model cases of it?

- What are arguments that explain and evaluate it (p. 4)?

Perkins (1986) explained that such questions defined the difference between knowledge as information and knowledge as design. Using design thinking as a frame of reference opens "neglected opportunities for understanding and critical and creative thinking" (p. 3). Once again, the issue of appropriateness is integral to this definition with creative thinking linked to critical thinking.

Cross's (2006) idea that design thinking involves work with non-verbal modeling media has support in the studies of Wilson (1998), and the earlier work of McKim (1972). Neuroscientist Wilson (1998) traced the ways in which our hands have influenced our cognitive development. He established an evolutionary link between our use and design of tools and the development of language and thought. Wilson argued that the evolution of the human hand (i.e., with an opposable thumb) presented not only the mechanical potential for tool use, but also "an impetus to redesign" the brain's circuitry in accordance with its need to control locomotion (p. 59). He goes on to cite ideas regarding language development, including Vygotsky's[2] notion that the brain treats words as though they are real objects, forming them into small groups much as we sort blocks or other objects in the physical world. Wilson asserted that the thought-language nexus becomes a hand-thought-language nexus as a child matures:

> The child learns with real objects, by trial and error, to make constructions that are inevitably composed of discrete events unified through a sequence of actions. Playing with anything to make something is always paralleled in cognition by the creation of a story. (p. 195)

The concrete nature of objects and how they go together in time (i.e., beginning, middle, and ending actions) are the subject matter of that story.

In a closing chapter, Wilson (1998) summarized what this link means for education and cited the work of Jeanne Bamberger, who founded the *Laboratory for Making Things*. Bamberger described a common phenomenon:

> Children who are most successful, even virtuosos, at using their hands to build and fix complicated things in the everyday world around them . . . are often the same children who are having the most difficulty learning in schools . . . . With an emphasis in schooling on symbolic knowledge, it is not surprising that attention focuses on what these children cannot do . . . 'hand knowledge' and

'symbolic knowledge' constitute equally powerful but different and not equally appreciated ways of organizing worldly phenomenon. (Wilson, 1998, p. 282)

Bamberger's work helped students to transition from building things to making verbal descriptions of what they were doing. She emphasized that many children do not have the problem of doing math; instead, they have the problem of representing it. It is precisely these alternate translations of thought to physical form that characterize design thinking. Modeling and diagramming are simply alternate forms for representing and manipulating ideas.

Unfortunately, as students progress in age, schools are less tolerant of such physical alternatives and in today's world of work few adults use their hands for little more than typing on a keyboard. Classes in design and technology are among the few places in the school curriculum, especially at the secondary level, where concrete experiences are considered an acceptable form of instruction. Wilson's (1998) work, therefore, made a strong case for the evolutionary origins of our need to make things and its continued importance in learning experiences.

McKim (1972) is best known for his explanations of visual thinking. He described three conditions that foster productive thinking:

- *Challenge:* We think best when confronted with circumstances that we deeply wish to change.
- *Information:* We need to process content that is correct and relevant.
- *Flexibility:* We need to have access to subconscious as well as conscious levels of thinking, be proficient at a number of operations, and utilize several vehicles of thought (p. 2).

It is flexibility that we most typically associate with design thinking. Flexibility in *operations* refers to our ability to move back and forth among (a) analysis (i.e., dissecting the object of our thinking into parts); (b) synthesis (i.e., actively combining two or more unlike ideas); (c) induction (i.e., working from specific to general); and (d) deduction (i.e., working from general to specific; McKim, 1972, p. 2). It is easy to imagine student design projects that encourage these various operations, but too frequently school experiences favor one operation, (e.g., analysis) over the others, reminding us of Sternberg's (1999) warning that such abilities must be in balance for good ideas to flourish.

McKim's (1972) discussion of *vehicles* of thought is especially relevant to teaching and learning in design. He referred to the means by which thinking operations are represented to our consciousness (i.e., in language, numbers, feelings, and imagery; p. 3). This concept is not unlike Gardner's (1983) theory of multiple intelligences, which has garnered so much attention in schools. McKim suggested that visual thinking is carried out by three kinds of imagery: (a) the kind we see; (b) the kind we imagine in our mind's eye; and (c) the kind we draw or make (p. 6).

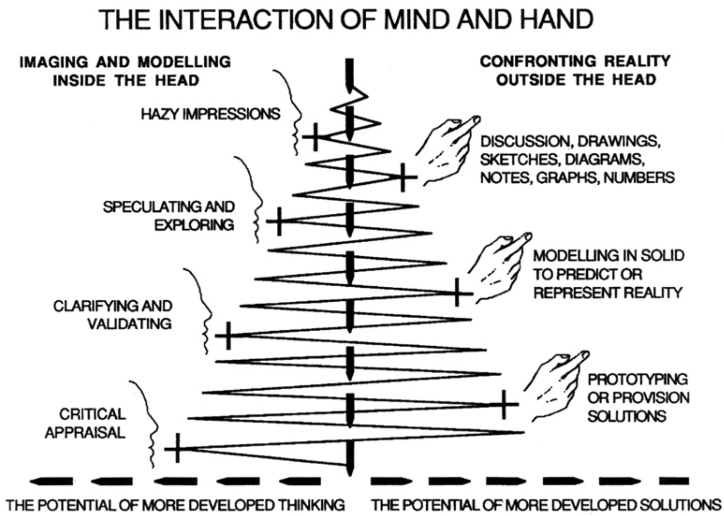
This distinction is important, because while the three kinds of imagery interact, schools pay much less attention to imagination and drawing than to observation. For example, students may be encouraged to read diagrams in textbooks but not to imagine and construct them as their own visual representations of data. When they are asked to draw, the task is often absent of guiding principles for the critique of that visualization (e.g., that graduated rather than random color in a map may represent increasing percentages of voter participation in various locations or that a bar chart will better communicate gain and loss when vertical than horizontal). Today's software further discourages making judgments about visual form by putting absolutely any data into a pie chart, whether or not the intent is a parts-to-whole comparison. In constructing their own representations, students must weigh options and make judgments about the relationship between the data and its representational form, thus suggesting a deeper engagement with content.

McKim (1972) cited psychiatrist Lawrence Kubie's belief that thinking cannot be taught and that it is something we do naturally. The ultimate goal of education, therefore, is about "how not to interfere with the inherent capacity of the human mind to think" (p. 23). McKim provides dozens of activities intended to flex the already-present muscles of imagination and drawing and to build a repertoire of visual thinking that co-exists with the linguistic and computational approaches that dominate student work in K-12 schools.

If we agree that visual thinking is an important competency, especially in a world of increasingly visual information, then the next question is: *Which component of the K-12 curriculum is responsible for cultivating visual thinkers?* Most would say all components of the curriculum bear some responsibility for addressing the issues of representation, but just as language is used everywhere but taught primarily in English classes, there needs to be a discipline that supports students' visual thinking as an explicit curricular obligation. It would seem logical to locate such instruction in the visual arts, but for many students, enrollment in art classes is not an option. Funding shortfalls for the arts and the tendency to favor students who demonstrate technical mastery leave many students without a visual component to their education. Further, visual arts instruction frequently promotes the highly romanticized notions of creativity mentioned at the front of this chapter; the applied problems of information translation are seen as secondary to the "higher" goal of self-expression. Therefore, students see drawing only as a vehicle for capturing emotion, not data, or as requiring some proficiency in technique to qualify as effective communication. The focus in many art classes, as a result, is the use of sketching or drawing as a summative means of presentation, not as a formative means of ideation or information manipulation that may be of value at various times throughout the problem solving process. It is appropriate, therefore, for design and technology education to assume responsibility for exercising students' visual thinking skills; for developing in students the expanded repertoire of thinking abilities that include imagery, as well as language and numbers.

In Great Britain, the School Examination and Assessment Council described the role of sketches and models in the work of designers, believing the hand/mind relationship is one of oscillation between internal and external representations (Kimbell, Stables, Wheeler, Wozniak, & Kelly, 1991, p. 20; see Figure 1, next page). Kimbell, et al. said designers begin with hazy visual impressions of the problem and externalize them in annotated drawings, diagrams, and other graphic forms. Through such artifacts they detect patterns, explore relationships, and compare data. Exploratory activities of this kind are difficult to perform entirely in the mind, especially while also retaining original ideas about the problem, so the external representations embody concepts in forms that can be manipulated. After thinking about and evaluating what they see in these exploratory images, designers often construct models that represent what the solution to the problem will look like when built. Another round of thinking clarifies that the relationships among physical elements and properties are appropriate. The designer often imagines in the mind's eye those modifications that will resolve any perceived shortfalls. He/she then takes the work back into the external world through a prototype, a full-scale facsimile of the real thing that may be tested with users. Such outcomes undergo the final critical appraisal by the designer, which informs thinking about future design problems.

Figure 1. A Conceptual Model of the Interaction Between the Mind and the Hand Throughout the Design Process



Source: Goldsmiths, University of London, Department of Design, Technology Education Research Unit (TERU) website. Originally from the book *The Assessment of Performance in Design and Technology* (1991) sponsored by the Secondary Examinations and Assessment Council and Her Majesty's Stationary Office (HMSO). Used with permission. Accessed on July 12, 2010 at http://www.gold.ac.uk/teru/projectinfo/projecttitle,5893,en.php

Kimbell, et al.'s (1991) concept of design thinking, therefore, is consistent with McKim's (1972) description of visual thinking. The process of design is a back-and-forth dialogue between images in the mind and tangible representations in the concrete world. Not all representations in this process need rise to the level of finished products (e.g., the massing of form in a building can be well-understood through models constructed of simple wooden shapes or even empty *Jello* boxes and sugar cubes). The goal is to move thinking to the next step.

College-level architecture and design programs develop this hand/mind interaction in studio classes, often as a way for students to test the viability of possible solutions to complex problems.

Architecture professor Lawson's (1990) research confirmed that the way in which we frame such process-based learning experiences has an impact on the characteristic problem solving strategies of students as they leave school. As Dean of Faculty in Architectural Studies at the University of Sheffield, Lawson studied two groups of students: architects and engineers. While architecture and engineering share much subject matter in common, the typical pedagogical strategies in the two college majors are very different. Engineering courses generally involve large-enrollment lecture courses paired with smaller, exercise-oriented labs for as many as 60 students. Assignments demonstrate basic engineering principles and have conceptual scaffolding, increasing in complexity and difficulty across the semester. Architecture studios are activity-based, meet for many hours at a time, and enroll only 12-15 students under a single instructor. Projects are open-ended and the process for developing solutions is iterative as projects shift in emphasis across the semester, but most are comprehensive in scope.

Giving seniors in each discipline the same task (i.e., to identify a set of unknown rules for the arrangement of differently colored blocks), Lawson (1990) discovered contrasting approaches to the problem demonstrated by the two disciplinary groups. The engineers began by generating all possible combinations for the arrangement of blocks, while the architects proposed rules and then tested them through various configurations. In other words, the engineers were problem oriented while the architects were solution oriented. Lawson then conducted the same experiment with freshmen in the two majors, but found no differences between their problem-solving strategies. Thus, he concluded that the approaches of seniors resulted from how they were taught across their four years of study. We can assume, therefore, that how we teach has as much impact on students' perceptions of problems and the development of problem solving strategies as what we teach.

DESIGNERS' PERCEPTIONS OF PROBLEMS

Around the same time as work in Great Britain attempted to deconstruct the nature of design thinking, Americans Alexander and Simon addressed issues surrounding designers' perceptions of problems. Architect Alexander (1964) made a strong case for design as the "goodness of fit between form and context" (p. 15). He defined form as that which we can shape and context as the ensemble of factors to which we fit form. The task for the designer, therefore, is not simply innovation or novelty, but innovation that responds to a specific mix of physical, psychological, technological, cultural, social, and economic conditions. Design thinking, under this definition, responds to a situated problem. We can choose to address more or fewer of the factors that comprise the situation, but there is no design creativity or innovation to be judged except with respect to a context. For example:

- The cup in Figure 2 is well suited to drinking coffee while driving. It has a wide base and narrow rim, making it fairly stable. The small opening and thick stoneware allow it to retain heat through the duration of a driver's commute to work and a rubber bottom keeps it from sliding on slick surfaces.

Figure 2. A Ceramic Cup with Stability, Heat Retention, and Traction Suitable for Driving

Note. Photograph owned by author, used with permission.

- The cup in Figure 3 (next page) is a Heller mug designed by Massimo Vignelli. It is made of plastic with a beveled bottom that allows several cups to stack easily in the cupboard. The handle accommodates all five fingers and is convex where the human hand is concave and concave where the hand is convex. It is available in black, white, and primary colors suitable to casual dining and a modern aesthetic.

Figure 3. A Modern, Stackable Plastic Cup with Ergonomic Features Suitable for Casual Dining

Note. Photograph owned by author, used with permission.

- The cup in Figure 4 is my grandmother's china teacup. It has a very small base and a wide mouth, making it tipsy and sacrificing heat retention for a more graceful shape. The handle accommodates only the forefinger and thumb in a gesture that causes the pinkie finger to rise. Its "fussiness" (i.e., painted roses and gold trim) speaks to Old World notions of formality and elegance. Although very fragile, it has the qualities of something that families pass from generation to generation.

Figure 4. A Fine China Teacup Representative of High Culture and Heritage

Note. Photograph owned by author, used with permission.

- The cup in Figure 5 is a Solo cup. It is made of thin plastic and unstable when empty. The ridges on the side of the cup improve traction when cold liquids cause it to sweat. It nests with others of its kind, consuming little space on supermarket shelves or in picnic coolers. And, it is cheap and disposable.

Figure 5. A Disposable Plastic Picnic Cup Having Temporary Utility

Note. Photograph owned by author, used with permission.

These four cups respond to different problem contexts: driving, casual dining, expression of high culture and heritage, and temporary utility. In meeting the particular demands of these contexts, the cup designers had to ignore others. It is a tough problem to be both stackable *and* retain heat or to be both disposable *and* elegant. To do so requires compromise in the resolution of competing priorities.

Now think about the design problem of containing liquid for drinking. Instantly the scope of the problem context expands beyond the more narrow range of conditions that influence the design of a cup. What kinds of liquid, for whom, and under what conditions? Drink boxes, canteens, squeeze bottles, and freezer pops are just a few contemporary responses to a context only slightly broader than that of a cup. Had the designers of these objects viewed their respective problems as yet another cup, rather than another way of drinking, these objects would not be a part of our product world (Davis, in press).

In these examples, therefore, evidence of design thinking resides not just in the properties of the cup but also in the definition of the problem itself (i.e., in the articulation of the conditions for which the cup was designed). We can critique the formal solution, but to do so, we must also consider the designer's choices about what to include and what not to include in the problem definition.

The work of Nobel Prize winner Herb Simon spanned the issues of economics, psychology, computer science, and design in his work. Simon (1969) described design as devising "courses of action aimed at changing existing situations into preferred ones" (p. 111). Simon divided the world into the natural sciences (e.g., physics), which are concerned with how things are, and the artificial sciences (e.g., design and engineering), which are concerned with how things ought to be. While he went on to recommend decision-making strategies aimed at optimizing conditions in the artificial world, the underlying premise of his work was that choices, including those of technology, arise from values-driven priorities about attaining goals. Strategy and technology, in this sense, are not neutral; they represent commitment to deliberate means of action with expectations of reaching some preferred end. What characterizes the thinking of designers, therefore, is the ability to imagine those preferred conditions before actually building them. The designer visualizes in the mind's eye or simulates a solution and its consequences without first expending the resources necessary to execute the final product.

To engage in design thinking under Simon's (1969) definition, therefore, is to understand technology (e.g., software and other ways of doing something) within the context of making things more usable, useful, desirable, viable, or sustainable. The artifacts of design activity cannot be evaluated entirely by their obvious craft (i.e., mastery of material) or expressive qualities (e.g., how elegant, funky, or poetic they appear), but instead, by a logic of form, which suggests that value judgments were made with the intention to achieve some preferred state of being. In other words, the scope of relevant performance in designing a creative solution to a problem includes the interactions between people and their surrounding environment that the object makes possible.

MAKING THE CASE FOR CREATIVITY AND DESIGN THINKING

Explicit government and private support for fostering students' creativity and design thinking skills can be found as early as 1992, when the U.S. Department of Labor issued the report from The Secretary's Commission on Achieving Necessary Skills (SCANS). Representatives from business, education, labor, and government identified the skills and competencies necessary for productive workers in the high-wage, high-skill employment of the 21st century. Competencies for productive work included the use of resources, information, systems, and technology. Clearly, addressing design problems requires these same competencies. SCANS also called for the mastery of various thinking skills, including creative thinking, decision-making, problem solving, and seeing things in the mind's eye. This is an enlightened list of skills in its separation of various types of problem-based work (e.g., it recognizes that not all problem solving is creative) and in valuing the ability to imagine solutions, irrespective of the content of that visualization (Davis, Hawley, McMullan, & Spilka, 1997).

There are, however, certain conditions in contemporary society that underlie assumptions in the SCANS report, and more specifically, that argue for the roles design education can play in encouraging students to think creatively. These conditions include

- an increasing complexity in the nature of problems;
- acceleration in the pace of change, particularly with respect to technology; and
- a shift in control of technology from centralized experts to users (Davis, 2008a, 2008b).

Increasing complexity. Today's problems are exceedingly complex. The current world financial crisis and global warming demonstrate that changes in one aspect of life have ripple effects throughout networks of interdependent systems. In some periods of our history, the role of engineering and design was to reduce our awareness of this complexity (i.e., to present simplified representations of complex systems that allowed us to go about our business without information overload). We could get from Fredericksburg, Virginia to Washington, DC in a comfy car on the interstate without having to fuss with the stop-and-go traffic of small towns or share the ride with strangers on the bus or train. Never mind that these same cars and roads divided neighborhoods with off-ramps, increased pollution, and used energy at rates well in excess of other countries, or that the average American now spends 221 hours a year commuting to work in a car. The jobs that supported this simplification effort were clearly defined: Engineers built roads, bridges, and dams; industrial designers styled cars; and bankers made loans. The dispositions and skills necessary to prepare for these jobs seemed stable and finite.

But as complexity increased, we came to understand the connectedness of things. Even if we do not know exactly how our computer works, for example, we do know that keeping it current is essential to work, social communication, and many forms of leisure; that it will continue to accelerate demands on our time; and that disposing of it has environmental implications. We notice that while the size of this technology continues to shrink, the number of features, amount of information, and sheer volume of stuff related to computing expands exponentially.

The design problem in post-industrial society, therefore, is not to simplify this complexity (we are too addicted to its benefits) but to manage it intelligently and responsibly. And because no single discipline has the full range of intellectual resources to accomplish tasks of this scale, the work falls to non-hierarchical, interdisciplinary teams. Work is no longer only about if we can engineer the dam, but also about understanding and reconciling its impact on the ecosystem, anticipating the business and social implications of redistributing water, planning for disaster and climate change, building consensus on the project with surrounding communities, and a myriad of other concerns.

Unfortunately, the world of work that K-12 students will enter in the coming decades has few paradigms for solving problems of this magnitude and not much history of collaborating in teams with flat hierarchies. Students will have to bring creativity to the solution of problems and to the invention of new methods for working together.

Accelerating change. The pace of change, particularly technological change, is another characteristic of life in the 21st century. New technologies tend to enter our world in the form of older technologies (e.g., the personal computer arrived as a typewriter keyboard and a television). But, quickly they change form and media converge in increasingly smaller devices. Many cell phones now contain all the functions of a personal computer, as well as video cameras, tape recorders, telephone directories, and other information technologies. New materials make previously unseen structures possible and extend the life of objects and environments.

This change is a challenge for technology instruction and places demands on students for flexible thinking skills. How do we prepare students for change that is this rapid? It is not about the next iteration of Photoshop, but about the ubiquitous presence of technology in our lives and how that presence changes everything around it. Sensors, for example, are now hidden throughout our environment and activated by conscious and unconscious gestures or voice. What happens when our interface with technology, which historically has been all about graphic representations and hardware, disappears? How do we design smart buildings that can adapt to these changes and when the technological infrastructure buried deep within concrete walls will not outlive the building?

Design strategist Dubberly (2008) described a shift from a mechanical to an organic design process brought about by changes in technology. A mechanical process is managed from top-down and the end state of the work produced is *almost perfect*. If we are designing a chair, a backpack, or a brochure, for example, the task is to refine the concept to its most effective form and then go into the mass production of duplicates. We can design and build another kind of chair, but doing so has no impact on the original version and we will renegotiate all the steps of design and approval required for the first chair. Under an organic design process, the process is managed from bottom up and the end state is *good enough for now*. The website design of amazon.com arises from the book-buying behaviors and preferences of users and evolves over time, as demands for certain functions emerge and become known. Organic design processes create platforms that are extendable and the role of the designer is as a creator of tools and systems. Amazon recently added the Kindle, which delivers entire books to a hand-held device in 60 seconds. Consumers now acquire literature as easily as they select a television channel.

Change, therefore, calls for new ways of designing and constant updates of skills and knowledge. The task for students is not just learning how to learn because knowledge is dynamic, but also anticipating when a new paradigm for learning is necessary.

Shift in control. Decentralized problem solving and rapid technological change argue for designing tools and systems rather than single solutions; thus, means rather than ends. There is ample evidence that we live in a do-it-yourself, customizable society. The furniture company, IKEA, has “outsourced” interior design and factory construction to the consumer through modular systems that are assembled and combined after purchase. Networking sites, such as Facebook, provide the tools and systems for social interaction but leave the content generation to users. Apple's *iTunes* circumvents the control of artists and record companies by allowing music lovers to build their own playlists, a song at a time in any order they choose. Software, such as Microsoft's *Photosynth*, (http://livelabs.com), builds amazing simulations of places like Notre Dame Cathedral by grabbing bits and bytes of images from everyone's photos on *flickr*, the photo archiving/sharing site.

We live in a participatory culture that transfers increasing amounts of control for highly specialized products and services to ordinary people. This shift in control places increasing responsibility for creative thinking on users, who now fully expect the privilege to adapt tools and systems to their own purposes. There is greater obligation for designers and engineers to design with people, not for them. This sharing of control calls for changes in the methods by which we explore people's attitudes, behaviors, and desires.

Human factors is the study of the human-machine interface and guides the development of most consumer technology. Subjects sit in front of computer screens in labs and demonstrate to experts that they are able to perform the functions demanded by the technology. Every point and click is timed and measured. Recent thinking, however, expands the scope of user research to include the motives and activities that bring people to technology in the first place.

Design researcher Liz Sanders develops what she calls *convivial tools*.[3] Convivial tools allow co-creators to speculate about and invent functions and applications for technology in their everyday lives. Instead of asking people what new functions the computer can perform in the home, for example, Sanders asked people what they want to do in their homes and then left it to technologists to figure out how the computer can assist. To determine consumers' wants and desires, she gave each person a rectangular piece of foam with Velcro-backed buttons. They built a remote control and then Sanders asked them to describe what the buttons would control.

A similar exercise was done during the spring 2008 with middle school design and technology students under North Carolina State graduate student, Michele Wong Kung Fong. She had developed an interactive software program that explains the anatomy of the human heart as support for a science lesson. She asked students to build a remote control for interacting with the program, detailing what they wanted the buttons to do. Figure 6 shows a couple of responses. Had she simply asked students what they thought of the program, as might happen in typical focus group testing, Wong Kung Fong would not have learned that students wanted to see the heart under stress, to compare it with the hearts of other species, and to understand the progression of heart disease on its function. The convivial tools made such responses possible. What this example demonstrates is that adaptable and adaptive technology will develop under design methods that acknowledge the participatory nature and expectations of creative control characterizing our contemporary culture.

Figure 6. Two Designs Prepared by Middle School Students for Interactive Remote Control Software to Explain the Anatomy of the Heart

Source: Master's thesis *Interactive Tools for a Remote and Synchronous Mentoring Interface* by Michele Wong Kung Fong, (2008), North Carolina State University, Raleigh, North Carolin. Used with permission.

CHARACTERISTICS OF DESIGN CHALLENGES THAT SUPPORT STUDENTS' CREATIVE DEVELOPMENT

Given the very specific characteristics of creativity, innovation, and design thinking and the conditions that define 21st century work, it is important to give careful consideration to the attributes of problems (i.e., learning experiences) and settings that nurture students' thinking skills. Unfortunately, schools often translate *active learning* and *project-based education* as a series of standard exercises that produce a limited range of skill sets and possible artifacts for all students: Everyone makes the same birdhouse, drafts plans for a three-bedroom ranch house, or designs business cards for other eighth graders. Students are active and undertake real-world projects, but little about the demands on thinking resembles the creative behaviors previously mentioned and called for by contemporary work and life. Further, the structure of the school day frequently fragments such projects across time into steps that isolate certain types of thinking within categories of activity or truncate the full range of mental steps (i.e., preparation, incubation, insight, evaluation, and elaboration) necessary to achieve creative results. Creativity is rarely seen as applicable to project research or the choice of materials, for example. Instead, teachers often believe it resides only in the sketching phase of the project.

Regardless of purpose or content, good design challenges share the following characteristics:

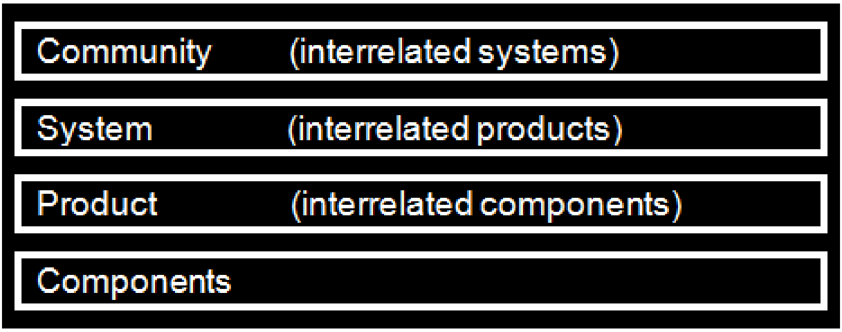
- *Open-ended:* The solution to the problem is not known at the start of the assignment.
- *Situated:* The form of the solution arises from the conditions or circumstances surrounding its use. This form includes its physical, cognitive, cultural, technological, and economic dimensions.
- *Responsive:* The problem statement and outcome are accountable to more than the designer's own interests.
- *Values-laden:* The solution to the problem requires a ranking of competing priorities.
- *Integrative and holistic:* Solving the problem relies on information and skills from more than one discipline and proceeds from inception to evaluation of outcomes.
- *Authentic in assessment strategies:* The methods for generating and evaluating ideas are congruent with the constraints and affordances of the problem.

Open-ended. Design problems are by nature, uncertain; neither teachers nor students know the specific characteristics of solutions before the project begins. These problems can describe how good solutions must perform (e.g., seating must support human weight), but there are many ways to provide that performance. Consequently, we are not likely to incite design thinking through projects that are inherently prescriptive of particular solutions. This open-endedness is not to suggest that common learning outcomes cannot be achieved or that particular technical skills cannot be taught. Instead, it means that such outcomes and skills are not described in terms of a singular product, but in terms of the experiences through which many kinds of products may be created. The problem is not to draft that three-bedroom house; however, it is to understand how drafting represents three-dimensional space in two-dimensional form (i.e., plan, elevation, and section) and communicates the organization and qualities of built form to a client and a workforce that will construct it.

If taught with these goals in mind, rather than that of drafting a house or any other object, an appropriate activity might reasonably ask the student to construct a three-dimensional object and draft it so that another student could build it again, solely from the drawings. In such a project, no two drafting tasks would be the same and students would construct the objects with the communication responsibility in mind. Their drawings would be informed by their building experiences, which is not the case in drafting a hypothetical house. Creativity would be brought to bear on an aspect of design and technology that is more typically seen as a mere technical skill (i.e., drafting) that follows a more creative task (i.e., designing). In other words, the problems of visually representing and communicating form through drafting, not just that of designing the object to be drafted, would demand creative thinking. Such thinking can be evaluated using common standards, even though students use different objects as source material for the drafted work. Eventually, it may be important for students to know principles for the organization of residential space and its construction, but those are problems different from representing such issues in drafted form.

Situated. Design methodologist Jones (1970) wrote about the scales at which design problems exist (see Figure 7, next page). At the bottom of the hierarchy are components and products while at the top are systems (i.e., interrelated products) and communities (i.e., interrelated systems) where the issues of post-industrial society generally reside. We can think of an automobile in terms of its wheels and axles; as a product for getting us from point A to B; as a transportation choice within a larger system that includes bicycles, buses, and trains; or as part of a complex network of various systems that determine where we live, the quality of the air we breathe, and our dependency on foreign oil. Unfortunately, when designing the automobile, American companies have tended to rely on problem solving methods better suited to the lower end of the hierarchy (i.e., components and products) than to the higher levels of systems and communities.

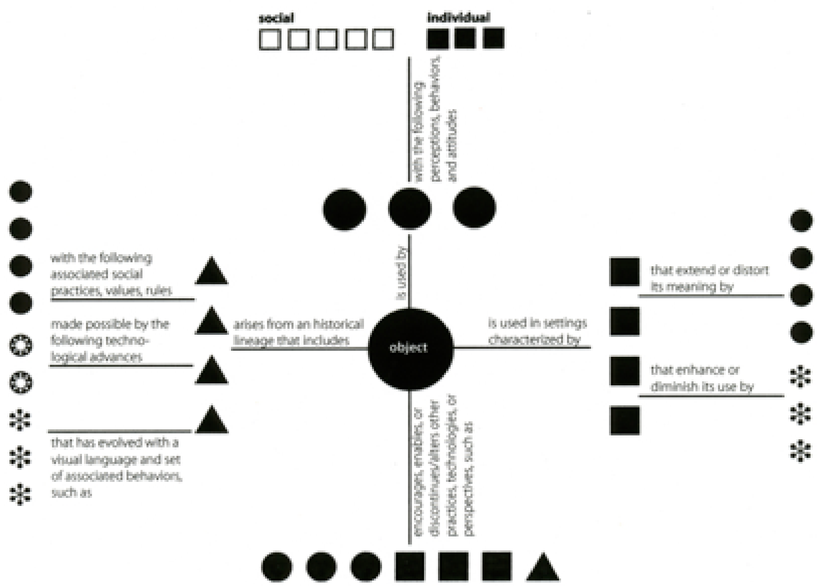
Figure 7. My Graphic Representation of the Hierarchy of Design Problems as Developed by J. Christopher Jones (1970)



When we talk about design problems as being situated, we refer to a much larger set of issues than those of simple use and the immediate physical surroundings. Figure 8 (next page), for example, shows a way of talking with students about the larger context for which creative solutions are necessary. The iPod is a technological object with relationships to a number of systems. We can think of it, historically and culturally, as the current terminus of a technological timeline of music listening. We can talk about it as connecting us to a larger social world through the Internet and file sharing, while at the same time isolating us socially from people sitting in the same room. We recognize that it changed how the recording industry does business and artists' control over how we listen to albums. We can explain its success over other MP3 players, because Apple nested the technological product within an economic system (i.e., iTunes). We also can identify a range of other products that build upon the iPod for their cultural identity (e.g., the youth-oriented Toyota Yaris was originally advertised as being "iPod compatible"). The true creativity in the design of the iPod, therefore, lies not only in its engineering and cool form, but also in the designers understanding the potential of the object for changing larger systems.

Further, by situating problems in real contexts we encourage students to extract relevant information from the setting, which enables them to search for and define conditions that guide the solutions to problems, rather than simply to respond to parameters listed in a project brief. For example, the *Fish Taxi* assignment asks students to design an effective way for transporting live goldfish from the pet store to home while riding a bicycle with both hands. Students can easily inventory where on the bicycle or body the "package" might rest, the forces affecting its movement, and the consequences for the fish. Even if we remove the traditional plastic bag as a solution, the principles that make the bag appropriate as a solution are known and provide creative inspiration for other alternatives. The answers to the problem, therefore, lie in making creative use of the circumstances, all of which are present in the problem setting.

Figure 8. Placing a Designed Object Within Multiple Contexts



Note. Graphic owned by author, used with permission.

Responsive. The *Fish Taxi* illustrates another point: design solutions often respond to needs that are very different from those of the designer. The cyclist is simply the means of locomotion and it is the fish whose needs determine the solution to the problem. There are many types of accountability. Sustainable design is accountable for our cradle-to-grave use of the earth's resources. Interactive web design is accountable for human-centered solutions in a program-driven, machine-centered world. Service design is accountable for the quality of planning and organization of people, infrastructure, and communication that surround consumer products.

Wiggins and McTighe (1998) identified six facets of understanding. The ability to explain, interpret, and apply knowledge are fairly typical objectives of K-12 curricula. Holding a perspective, developing empathy, and gaining a meta-view of one's own learning are less likely. What these higher-level behaviors share in common, however, is an awareness of others' and one's own position among many possible viewpoints on the world. Design projects can ask students to step outside their comfort zone, to walk in someone else's shoes as a means for shaping such dispositions.

Design for the Other 90% is an exhibition by the Cooper Hewitt National Design Museum. The corresponding website captioned the exhibition by saying:

> Of the world's total population of 6.5 billion, 5.8 billion people, or 90%, have little or no access to most of the products and services many of us take for granted; in fact, nearly half do not have regular access to food, clean water, or shelter. *Design for the Other 90%* [italics added] explores a growing movement among designers to design low-cost solutions for this 'other 90%.' (Cooper Hewitt, para. 1)

Solutions include a drinking straw that purifies water from the stream to mouth; foot and below-knee prostheses for landmine-affected countries; solar lighting systems for people who live off the electric grid; and the Q Drum, a container for transporting water from public facilities by rolling it along the ground, rather than lifting or carrying. In addition to illustrating user-appropriate design innovations, the Cooper Hewitt Education Resource Center (http://www.educatorresourcecenter.org/) contains hundreds of teacher-authored design lesson plans. Many of these lesson plans place the student designer in unfamiliar territory.

Designers often learn about the people for whom they design through scenarios and personas. Scenarios are stories or scripts for projected action; they break down the activities and behaviors of users into narrative episodes that describe what a user is trying to achieve and the conditions and sequence of steps under which he or she is likely to achieve it. Personas are descriptions of actual or composited people with particular social roles, preferences, and values that allow the designer to think of user interactions with designed objects in terms of specific motives and behaviors. A legal secretary, for example, uses word-processing software differently from a writer of fiction. A senior citizen with limited dexterity exerts different physical forces on hand tools than the able-bodied carpenter. For the chatty teenager, the cell phone is a social necessity, while it is an emergency lifeline for the single female driver. Asking students to author scenarios and personas frames the problem-solving task in human terms and establishes the criteria for success under prototype testing conditions. Scenarios also translate well in storyboards, a method also used by animators and filmmakers to show key frames of action in a story. They provide the basis for prototyping media or interactive experiences in which events unfold over time.

Values-laden. An aspect of designing for people who are not like us is recognizing alternate or competing value systems. There is no bias-free design, because any choice to privilege one set of values over another is a subjective decision. Does the design of a tool sacrifice usability for beauty? Can it accommodate users who have physical limitations? Does its design consume resources that are scarce, and is there a recycling plan when it becomes broken or obsolete? Does its design encourage consumers to spend more by relating its form to a collection of other matching tools?

Unfortunately, design problems are too often stripped of complexity so that students never recognize or are asked to resolve these competing priorities. Objects are defined only in terms of their immediate physical function and the technical skills necessary for fabrication or construction. There is a difference, for example, between asking a student to design a stool and asking him to design a stool that can be cut in multiples from a 4’ x 8’ sheet of plywood with no waste and shipped flat to disaster areas for later assembly without using power tools. Also, there is a difference between building a personal website and designing an Internet “intervention” (i.e., blog, pop-up window, web banner, or blast email) that persuades teens to stay in school.

Further, design problems can illustrate that technologies also have inherent biases and are a product of their times and the people who invented them. The way in which Adobe InDesign software works, for example, encourages a modernist design sensibility closely associated with mid-twentieth century values in information design in which text boxes and grids invite students to compose layouts with certain proportional and alignment characteristics among text and images. Illustrator, on the other hand, does not have this bias, because text can be set without a grid. Further, in setting up the grid, the InDesign software asks users to set the dimensions of margins and columns, when the legibility of typography is actually determined by column width and the number of characters of type it accommodates. Too narrow a column and we get irregular spacing, too wide and the eye cannot find the start of the next sentence at the left of the paragraph. In this instance, the software design privileges the easier programming decision over the more critical visual decision; the width of columns is defined as the space “left over” after setting the margins. We must consciously overcome that programming bias by judging whether columns are too wide or too narrow for easy reading.

The layering and filtering potential of Adobe Photoshop has spawned a lifetime of complex, diffused images that speak as much about the technology as about the subject matter of the images. Photoshop has also changed our belief in the documentary truth of photography. If something can be so easily and convincingly altered, in what cases is seeing the same as believing?

Other software converts numerical data into bar charts for quantitative comparison. Imagine a company with five successive years of declining profit. If the bar chart in their annual report is vertical, the pattern of loss is apparent. On the other hand, if the bars are horizontal we are less likely to notice declining performance, because we do not have left/right associations with *gain* and *loss*. In this case, the seemingly objective form produced through mechanical means, a bar chart, can further a company’s subjective intent to subvert accurate reading.

The role of design projects, therefore, is to help students identify what values are relevant to the problem, where they reside in the problem context, how to reconcile them when they are in competition, and what impact choices have on final outcomes.

Integrative and holistic. Among the advantages of using design in K-12 classrooms is that design problems are inherently interdisciplinary and model problem solving in adult life. A carpenter does not go running to a mathematician in order to make calculations on the job site. A lawyer does not call an English major to author a brief. And, a friend does not consult a cartographer when describing how to get to her house on a cocktail napkin. Adults apply learning from a variety of fields in everyday work and in their personal lives. Only in schools do we ask students to behave one way in science and another way in language arts. Because design problems are situated in familiar contexts outside of the classroom, they require a range of knowledge and skills from various disciplines. This character makes them particularly well suited for integrating curriculum.

National voluntary content standards in various disciplines provide convenient entry points for integrating design and technology with other core subjects. *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993), for example, asked students to gain direct experience with materials and forces through design activity (pp. 187-191) and to analyze products and environments, identifying the problems they solve (pp. 41-57). Geography standards require that students consider how economy, culture, and technology shape the features of places (pp. 522-528) and "[understand] how human actions modify the physical environment" (p. 533; Kendall & Marzano, 1997). The *Standards for the English Language Arts* (National Council of Teachers of English and International Reading Association, 1996) extended the discipline's reach into territory previously assigned to visual arts. These standards charge students with presenting stories and information in non-print, visual media and using forms of visual representation in persuasive arguments (pp. 19-32). These explicit references to design and technology in the standards of other subject areas certainly suggest that technology instruction can contribute more than software expertise to interdisciplinary collaborations. But, they also signal that freestanding design and technology assignments can be more robust when targeting the applications of thinking in other fields.

Authentic in assessment strategies. First and foremost, good design problems embed the criteria for success in the students' efforts to define the problem. Architect Alexander (1964) said, "…when a designer does not understand a problem clearly enough to find the order it really calls for, he falls back on some arbitrarily chosen formal order [style]. The problem, because of its complexity, remains unsolved" (p. 1). By involving students in the articulation of the problem, the performances we expect of objects, and the student behaviors necessary to achieve them, are negotiated and public in the classroom. They arise from the problem itself, not from some unknown standard held only by the teacher.

It is tempting to assess students' creativity through the properties of the objects they make. The shortfalls in this approach became apparent in the 1990s when the British School Examinations and Assessment

Council (SEAC) assessed student achievement in design and technology. Under the direction of Kimbell, et al. (1991), the assessment reached agreement that design is "the purposeful pursuit of a task to some form of resolutions that results in improvement (for someone) in the made world" (p. 17) and that the made world was comprised of "products, systems, and the environments in which they function" (p. 18). There was less clarity, however, regarding the process of design. The team considered a number of models but had great reluctance to adopt descriptions that would reduce the creative process to a series of steps that "convert active capabilities into passive products" (p. 19). Ultimately, they settled on the description of mind/hand interaction, mentioned previously in this chapter, in which there is a back and forth dialogue between the imaging and modeling inside the head and the reality of representations in the physical world (see Figure 1).

In the British example, therefore, we see clear definitions of creativity and design as the various kinds of engagement of thinking and doing, not simply as the technical skill sets embedded in lesson plans or the physical attributes of the objects they produce (i.e., only the expressive right half of the diagram in Figure 8). The assessment team also cited the danger in assessing a creative mental activity, such as idea generation, by examining work products that relate only to one stage (e.g., sketching) in an ongoing process. The goal is to be creative at all times; in research, in choosing materials, in building the models and a prototype, and in all of the other processes involved with design They also acknowledged that it is as important for students to recognize what they need to know as much as it is to actually know it. As a result, the assessment of student performance in Great Britain focused more on why and how students chose to do things, on thought in action, rather than on what they chose to do.

This study argued, therefore, for holistic evaluation that is natural to the intentions and processes inherent in the problem-solving activity. Kimbell, et al.'s (1991) work provided an excellent road map for the authentic assessment of design projects.

THE CHALLENGE AHEAD

If design and technology education is to expand its responsibility to students beyond the mastery of technical processes, teachers must set an ambitious agenda with respect to creativity, innovation, and design thinking. Schools must build a culture in which making things is as important as writing and computation and in which high standards for the quality of ideas count as much as the quality of artifacts. This change process will not be easy; the preparation of teachers often favors mastery of subject matter and technique over real understanding. There is almost no history of design education for pre-service teachers; however, no other discipline is positioned as well to take on this challenge as technology education.

REFLECTIVE QUESTIONS

1. According to Csikszentmihalyi (1996), what are the three aspects of creativity that distinguish it from simple novelty and why are they important to someone teaching students how to be creative?
2. How does Cross's (2006) argument for design being considered the third academic discipline complement the case for technology and engineering education in the general curriculum?
3. What is the relationship between visual thinking skills and abilities and technological literacy?
4. Why would a technology and engineering teacher want to filter his or her classroom activities through the five design challenge characteristics of being open-ended, situated, responsive, values-laden, and integrative and holistic?

FOOTNOTES

[1]E. Paul Torrance, an American psychologist, developed tests of creative thinking based on fluency, flexibility, originality, and elaboration scales.

[2]For more information on Vygotsky, see Vygotsky, L. (1996). *Thought and language* (A. Kozulin, Trans. and Ed.). Cambridge, MA: MIT Press. (Original work published in Russian in 1934)

[3]Additional information on the writings of Elizabeth B.-N. Sanders and convivial tools can be accessed at http://maketools.com

REFERENCES

Alexander, C. (1964). *Notes on the synthesis of form*. Cambridge, MA: Harvard University Press.

American Association for the Advancement of Science. (1993). *Project 2061: Benchmarks for science literacy*. New York: Oxford University Press.

Cooper Hewitt National Design Museum. (n.d.). Design for the other 90%. Retrieved from http://other90.cooperhewitt.org/about/

Cross, N. (2006). *Designerly ways of knowing*. London: Springer.

Csikszentmihalyi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper Perennial.

Davis, M. (in press). *Design in context: An introduction to graphic design*. London: Thames and Hudson.

Davis, M. (1999, September/October). Design's inherent interdisciplinarity: The arts in integrated curricula. *Arts Education Policy Review, 101*(1), 8-14. Retrieved from http://www.ncsu.edu/www/ncsu/design/sod5/phd/resources/Davis_interdisciplinary.pdf

Davis, M. (2008a, September-October). Toto, I've got a feeling we're not in Kansas anymore… *Interactions Magazine, 15*(5), 28-34. Retrieved from http://portal.acm.org/citation.cfm?id=1390091

Davis, M. (2008b). Why do we need doctoral study in design? *International Journal of Design, 2*(3), 71-79. Retrieved from http://www.ijdesign.org/ojs/index.php/IJDesign/article/view/481/216

Davis, M., Hawley, P., McMullan, B., & Spilka, G. (1997). *Design as a catalyst for learning*. Alexandria, VA: Association for Supervision and Curriculum Development.

Dubberly, H. (2008, September 1). Design in the age of biology: Shifting from a mechanical-object ethos to an organic-systems ethos. *Interactions Magazine.* Retrieved from http://www.dubberly.com/articles/design-in-the-age-of-biology.html

Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic.

Jones, J. C. (1970). *Design methods: Seeds of human futures*. New York: Wiley Interscience.

Kelly, T. (2005). *The ten faces of innovation: IDEO's strategies for beating the devil's advocate and driving creativity throughout your organization*. New York: Doubleday.

Kendall, J. S., & Marzano, R. J. (1997). *Content Knowledge: A compendium of standards and benchmarks for K-12 education* (2nd ed.). Aurora, CO: Mid-continent Regional Educational Laboratory.

Kimbell, R., Stables, K., Wheeler, T., Wozniak, A., & Kelly, A. V. (1991). *The Assessment of Performance in Design and Technology*. London: SEAC/HMSO.

Lawson, B. (1990). *How designers think: The design process demystified*. Oxford, England: Butterworth Architecture.

McKim, R. (1972). *Experiences in visual thinking*. Monterey, CA: Brooks/Cole.

National Council of Teachers of English and International Reading Association. (1996). *Standards for the English language arts.* Urbana, IL: Author.

Perkins, D. N. (1986). *Knowledge as design*. Hillsdale, NJ: Lawrence Erlbaum.

Peters, T. (2003). *Re-imagine! Business excellence in a disruptive age*. New York: Dorling Kindersley.

Pink, D. (2005). *A whole new mind: Moving from the information age to the conceptual age*. New York: Riverhead.

Rosenman, M. & Gero, J. (1993). Creativity in design using a design prototype approach. In J. Gero and M. Maher (Eds.), *Modeling creativity and knowledge-based creative design* (pp. 111-138). Hillsdale, NJ: Lawrence Erlbaum.

Schwartz, R. (1987). Teaching for thinking: Developmental model for the infusion of thinking skills into mainstream instruction. In R. Sternberg (Ed.) *Teaching thinking skills: Theory and practice* (pp. 106-126). New York: W.H. Freeman and Company.

Secretary's Commission on Achieving Necessary Skills. (1992). *Learning a living: A blueprint for high performance scans report for America 2000*. Washington, DC: U.S. Department of Labor.

Simon, H. A. (1969). *The sciences of the artificial*. Cambridge, MA: MIT Press.

Sternberg, R. J. (Ed.). (1999). *Handbook of creativity*. New York: Cambridge University Press.

Wiggins, G. & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.

Wilson, F. R. (1998). *The hand: How its use shapes the brain, language, and culture*. New York: Pantheon.

Wong Kung Fong, M. (2008). *Interactive tools for a remote and synchronous mentoring interface* (Unpublished master's thesis). North Carolina State University, Raleigh, North Carolina.

The Knowledge and Skills of Creativity and Design

Chapter 7

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While many technology educators acknowledge that design is an essential element at the core of technological literacy (Lewis, 2005), how a technology educator implements key elements of design instruction in the classroom is still open to interpretation. This chapter seeks to identify the vital knowledge and skills that are necessary to effectively teach creativity and design. The literature and research about the critical knowledge and skills of creativity and design has indicated that a variety of questions remain unanswered. A variety of research studies that explored this construct will be examined in this chapter to help provide the reader with insight. The authors have also included in this chapter discussion of engineering design. As technology education embraces engineering as a focus, evident by the recent name change of the International Technology Education Association (ITEA) to the International Technology and Engineering Educators Association (ITEEA), it seems appropriate to also investigate the engineering design process and the knowledge and skills embedded within. Furthermore, the greatest debates regarding engineering design as a focus for technology education (Lewis, 2005) generates many questions about what are the critical knowledge and skills necessary to teach engineering design effectively. These key questions will also be addressed in this chapter.

IMPORTANCE OF KNOWLEDGE AND SKILLS FOR CREATIVITY AND DESIGN

A professional mechanic who is just starting a career may only have the basic tools of the trade in his or her toolbox. Those basic tools might include a set of screwdrivers, various wrenches, and maybe several types of hammers. That individual also starts out with a set amount of knowledge and skills that are based on his or her limited experiences. The base of knowledge, skills, and physical resources available limits how he or she solves problems as an automobile is repaired. With the passage of time the mechanic acquires more tools as well as more experience. These additional skills and knowledge expand the number of possible options to choose in solving any problem encountered while fixing a car. This example of a novice auto mechanic developing into one who is an expert briefly describes the same influence that one's skills and knowledge base has on the application of creativity and design.

Defining how experts differ from novices. Novices often get stuck in the problem definition stage and fail to generate solutions. Welch and Lim (2000) concluded that novice designers frequently get stuck in the problem space. Certainly, technology education programs can provide opportunities for students to learn how to search for multiple solutions and gather information from outside sources that lead to creative results. These creative design methods are an appropriate fit for the scope of technology education.

Cross's (2004) study of expertise in design found that expert engineers use solution driven strategies to approach engineering design problems. Cross wrote

> Expert designers are solution-focused, not problem-focused. This appears to be a feature of design cognition which comes with education and experience in designing. In particular, experience in a specific problem domain enables designers to move quickly to identifying a problem frame and proposing a solution conjecture. (p. 439)

Cross's studies of novice and expert designers revealed that many times expert designers use an integration of multiple design strategies (Cross, 2004; Kruger & Cross, 2001). Integrating strategies, or creating a *hybrid strategy*, is a technique often used by expert designers and engineers that should also be equally acceptable to the technology education community.

Expert ways of organizing, conceptualizing, and accessing knowledge and skills. The successful design firm IDEO often uses an information-driven approach to designing. An IDEO design team will, as part of their standard design process, study *experts* of a particular product they are attempting to innovate. The *experts* are the consumers and users of the products they are trying to redesign. The IDEO team will gather as much information from the *experts* as possible to bring back to the drawing board, often gathering vital information from the users of the technology, unobtainable from inside a design studio. Tom Kelley (2001) indicated that this method is helpful for the IDEO team to properly analyze existing designs so as to identify problems that need to be addressed in the redesign. Similarly, this method would make an excellent contribution to K-12 technology and engineering education programs, as many young designers might not possess valuable information about the product they are trying to redesign.

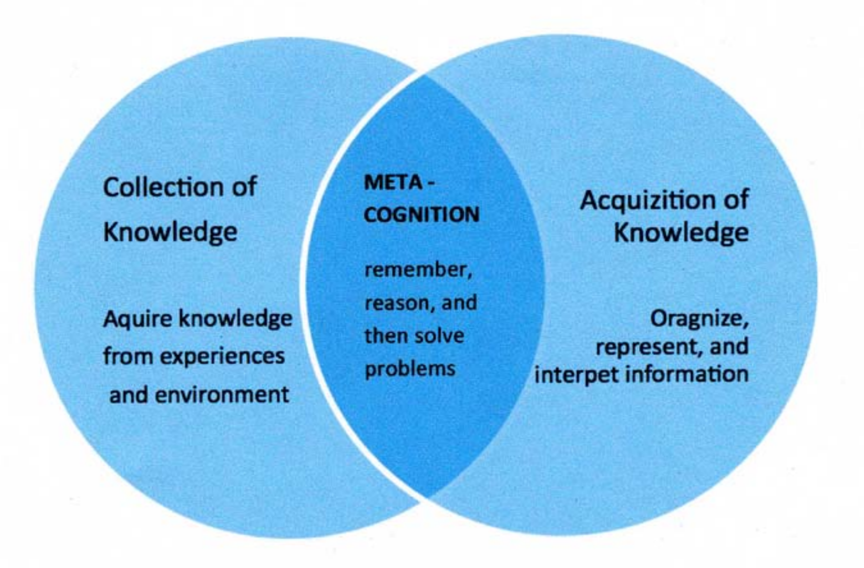
Role of meta-cognition. Design entails not only creative ability but analytical and practical skills as well. Design education requires a meta-cognitive approach to develop intuitive creative processes that can be made tangible for designers to reflect on prior experiences and knowledge, thus giving the designer an ability to solve any particular design challenge.

Psychologist Robert Sternberg's *Triarchic Theory of Human Intelligence* (Sternberg, 1988) made the argument that intelligent behavior is a balance between analytical, creative, and practical abilities, which allow students to achieve success within particular socio-cultural contexts. Analytical abilities enable students to evaluate, analyze, compare, and contrast information. Creative abilities generate invention, discovery, and other creative endeavors. Practical abilities allow students to apply what they have learned in the appropriate setting by bringing analytical and creative abilities together.

Successful students make the best use of analytical, creative, and practical strengths, while compensating for weaknesses they might have in any of these areas. A central feature of the triarchic theory of successful intelligence is adaptability, both within the individual and within the individual's socio-cultural context (Sternberg, 1994).

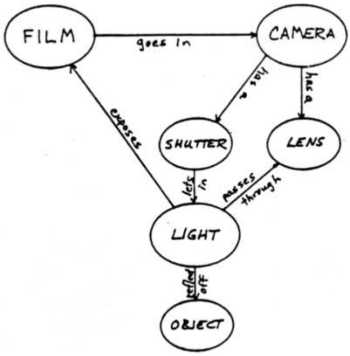
Bransford, Brown, and Cocking (1999) revealed that experts, by definition, are able to think effectively about problems in their areas of expertise and a meta-cognitive look at their methods reveals the nature of their thinking and problem solving. Experts have acquired knowledge that affects what they notice in their environment, and how they organize, represent, and interpret information. This is the key to their expert ability to remember, reason, and solve problems. Expert performance shows what the result of successful learning looks like (see Figure 1). Their skills of pattern recognition, deep understanding, and thorough knowledge of their disciplines suggest the processes of learning that can lead to the eventual development of expertise. Johnson and Thomas (1992) discussed the concept of expert and novice within the context of photography. To visually show the differences between a novice and an expert within a given subject area, Johnson and Thomas created a concept map of understanding for a novice student and an expert photographer (see Figure 2, next page). Arguably, advancements in design education will depend on increasing meta-cognitive awareness within students of often hidden processes of creativity and design.

Figure 1. A Graphic Representation of How an Expert in Any Field Acquires, Processes, and Uses Knowledge

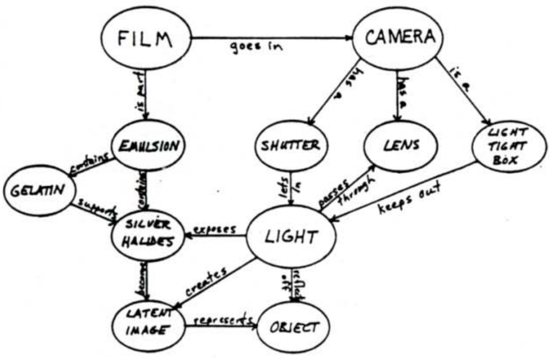


Note. Developed by Todd Kelley (2011) based upon the work of Bransford, Brown, and Cocking (1999).

Figure 2. The Differences Between a Novice Student and an Expert Photographer Toward an Understanding of the Subject Area of Photography



Inexperienced student's concept map.



More advanced student's concept map.

Source: "Technology Education and the Cognitive Revolution" by S. D. Johnson and R. Thomas (1992), *The Technology Teacher*, *51*, pp.7-12. Copyright 1992 by the International Technology Education Association.

CREATIVITY AND DESIGN LITERACY

Lewis (2005) provided a strong rationale suggesting that design is the single most important category in the *Standards for Technological Literacy* (*STL*; ITEA, 2000). Design, as a subject and as a process, as outlined in the *STL*, is considered a catalyst to explain and understand how all human-made things function. Lewis accurately identified that of the twenty standards, four directly address design. Understanding the cognitive strategies of designers is critical to developing curriculum that develops technologically literate individuals. The *STL* also identified the important role of design cognition: "To become literate in the design process requires acquiring the cognitive and procedural knowledge needed to create a design, in addition to familiarity with the processes by which a design will be carried out to make a product or system" (p. 90). Roberts (1994) emphasized "the purpose of teaching design is not to bring about change in the made world, but change in the student's cognitive skills" (p. 172). Furthermore, Jonassen (2000) made the case that ill-defined problems are difficult to solve, and thus require more cognitive operations than simpler, well-defined problems. Cross (2006) sought to identify for the education community the *designerly ways of knowing* embedded in the core of design experiences for education. He identified five aspects of designerly ways of knowing as follows:

- Designers tackle 'ill-defined' problems.
- Their mode of problem-solving is 'solution-focused'.
- Their mode of thinking is 'constructive'.
- They use 'codes' that translate abstract requirements into concrete objects.
- They use these codes to both 'read' and write in 'object' languages. (p. 29)

Cross also provided a rationale for design as a discipline within general education by providing three main areas of justification:

- Design develops innate abilities in solving real-world, ill-defined problems.
- Design sustains cognitive development in the concrete/iconic modes of cognition.
- Design offers opportunities for development of a wide range of abilities in nonverbal thought and communication. (2006, p. 30)

Johnson (1992) suggested a framework for technology education curricula that emphasizes intelligent processes. "Students should acquire a repertoire of cognitive and metacognitive skills and strategies that can be used when engaged in technological activity such as problem solving, decision making, and inquiry" (p. 30). Cognitive and metacognitive skills are important thinking processes required for design and problem solving, and these skills should be developed in technology education. Careful examination of the cognitive processes employed by students as they work through an ill-defined technical problem provides a means of evaluating the effectiveness of a curriculum approach designed to develop effective problem solvers.

UNIVERSAL COGNITIVE PROCESSES WITHIN CREATIVITY AND DESIGN

Now that a rationale has been presented on the benefits of providing design experiences that nurture and develop the student's cognitive and metacognitive capabilities, what are the important design cognitive capabilities? This question is more difficult than it might appear. Cross (2006) warned that expert designers might not be able to articulate what cognitive capabilities are necessary for creativity and design. Cross wrote

> What designers know about their own problem-solving processes remains largely tacit knowledge–i.e. they know it in the same way that a skilled person 'knows' how to perform that skill. They find it difficult to externalize their knowledge, and hence design education is forced to rely so heavily on an apprenticeship system of learning. (p. 25)

Cross indicated that this fact is problematic for design educators who are charged with articulating as clearly as possible what specific cognitive capabilities are essential for a student to become an expert designer.

The desire to generate a list of essential and universal design cognitive capabilities is captured in the dissertation work of Harold Halfin (1973). Halfin studied the writings of ten high-level designers including Charles Goodyear, Thomas Edison, Buckminster Fuller, Frank Lloyd Wright, and the Wright Brothers. His goal was to help identify the universal cognitive capabilities that existed in the lab notes and design diaries of those individuals. Halfin sought to identify the methods of inquiry used by these designers as they accumulated new knowledge. Halfin then created operational definitions that were submitted to a jury of experts for validation using a Delphi method. As shown in Table 1 (next page), the results of Halfin's study identified 17 mental processes that were universal for these experts.

Table 1. Cognitive Processes of Technical Designers

Mental Methods
Analyzing
Communicating
Computing
Creating
Defining problem(s)
Designing
Experimenting
Interpreting data
Managing
Measuring
Modeling
Models/prototypes
Observing
Predicting
Questions/hypotheses
Testing
Visualizing

Source: "Technology: A Process Approach" by H. Halfin (1973).

These 17 cognitive processes were later re-evaluated and updated by Wicklein and Rojewski (1999) to reaffirm Halfin's results through a modified Delphi method. Wicklein and Rojewski's study also identified an additional ten cognitive processes necessary for problem solving in an advancing technological society (see Table 2, next page). Hill and Wicklein (1999) used a factor analysis process on the revised Halfin code to identify five major themes that were typically employed when solving technical problems. The five themes that emerged were (a) *researching the problem*, (b) *searching for solutions*, (c) *innovation*, (d) *analyzing data*, and (e) *evaluating results*. The hope of the researchers in this study was that the factors identified would be appropriately integrated into the framework for technology education curricula. Hill (1997) developed a computer analysis tool called *Observation Procedure for Technology Education Mental Processes* (OPTEMP) as an assessment tool to evaluate design activities in technology education. Hill used the modified list from Halfin to code student's cognitive processes as they worked on design and problem solving activities in technology education classes.

Table 2. Ten Additional Mental Processes

Mental Methods
Contexts
Customer Analysis
Establishing Need
Innovating
Monitoring Data
Researching
Searching for Solutions
Technology Review
Transfer/Transformation
Values

Source: "Toward a Unified Curriculum Framework for Technology Education" by R. C. Wicklein and J. W. Rojewski (1999).

Todd Kelley (2008) conducted observational protocol studies on students participating in *Project Lead the Way* curriculum programs and with students participating in technology education programs partnering with the National Center for Engineering and Technology Education (NCETE). He observed students working through an ill-defined problem (i.e., the problem of moving drinking water in developing countries). A *think-aloud* protocol methodology was used to capture students' design thinking as the participants framed the problem. Kelley analyzed the data from these protocols using the Halfin (1973) list of universal cognitive processes and Hill's (1997) OPTEMP program, to accurately record frequency and duration of each mental process employed by the students. He also used the data from the protocol results to identify common cognitive strategies employed by the students to determine where these students placed the greatest emphasis throughout the observational protocol.

Previously, leaders within technology education (Hailey, Erickson, Becker, & Thomas, 2005; Wicklein, 2006) identified the ability to predict results of solutions as a missing piece in the technological design process. Basing his study, in part, on a previous work by Kruger and Cross (2001), Todd Kelley (2008) sought to identify missing or limited engagement of some cognitive processes. Within this study, students performed differently with respect to solving ill-defined problems when grouped by engineering focused programs. The results indicated that students did not use items, such as measuring and computing, from Halfin's list of cognitive processes that might lead to mathematical predictions. Furthermore, no participants used mathematical thinking to predict results of design solutions. The PLTW participants in general were more problem focused; whereas, the NCETE partner group participants were more solution driven.

As multiple K-12 engineering design curriculum projects continue to be implemented in schools across the country, more research studies need to be conducted to evaluate the effectiveness of such programs toward increasing students' cognitive abilities with respect to design. Furthermore, similar design and cognition studies within technology education should investigate the positive and negative impacts of engineering design curricula on students' creative thinking as they work through ill-defined design problems.

The Influence of Multiple Intelligence Theory. Gardner's (1983) theory of multiple intelligences lumped the visual world under a single term, *spatial* or sometimes *visual/spatial*, which includes the use of images (graphic design), objects (product design), and environments (architecture). Norden (2007) and Greenfield (1996) described the importance of visual stimuli as the primary sense. Though the sense of hearing may come in a close second place, "Much of the knowledge we acquire about the external world is derived from visual experience" (p. 50). Visual/spatial intelligence is, therefore, a critical cognitive process for design. Edwards in *Drawing on the Right Side of the Brain* (1999) embraced this knowledge of the importance of visual/spatial intelligence by addressing the act of drawing. Edwards observed that

> Drawing is a skill that can be learned by every normal person with average eyesight and average eye-hand coordination . . . . Learning to draw is more than the skill itself [it is learning] *how to see*. That is, you will learn how to process visual information in the special way used by artists. That way is *different* from the way you usually process visual information and seems to require that you use your brain in a different way than you ordinarily use it. (p. 3)

Shedroff's (2001) *experience design* and Moggridge's (2007) *interaction design*, attempt to improve how people use and experience a product or service by understanding the users' needs. These types of design could be thought of as incorporating elements of Gardner's identified interpersonal and intrapersonal intelligences. Thus, technology and engineer educators might include not only interactions between people (intrapersonal) and personal reflection (interpersonal), but also interactions between people and objects (e.g., interaction design, interface design, computer/human interface) in their programs.

Domain relevant and creativity relevant skills. Creative people and designers in particular often have traits such as the ability to suspend the desire to reach quick and easy solutions to problems, to generate many possible solutions, and to branch out in different directions in the search for potential design resolutions.

Lawson (2005) said that it is hardly surprising that good designers tend to be at ease with the lack of resolution of their ideas throughout most of the design process. Designers tend to either generate a series of alternatives to a challenge early on or focus on a set of alternatives and explore them exhaustively.

The ability to generate a number of potential solutions to a problem is referred to as *fluency* in the literature of creativity. Lawson (2005) stated, however, that creative thinkers in general and designers in particular have the ability to change the direction of their thinking to generate more ideas. This ability is referred to as *flexibility*.

Teresa Amabile heads the *Entrepreneurial Management Unit* at *Harvard Business School* and devotes her research program to the study of creativity in business. She collected nearly 12,000 daily journal entries from 238 people working on creative projects in seven companies in the consumer products, high-tech, and chemical industries. Preliminary results challenged commonly held beliefs about creative people. The common perception that some people are creative, and most are not, was found to be incorrect. Everyone with normal intelligence can be expected to produce novel and useful ideas. Creativity depends on experience, including knowledge and technical skills; talent, an ability to think in new ways; and the capacity to persist when confronted with uncreative dry spells. Intrinsic motivation is a characteristic of people who work creatively and money is not as much of a motivating factor as is often believed (Amabile, 1996).

LEARNING FROM EXPERTS ABOUT DESIGN

Bransford, Brown, and Cocking (1999) observed that experts, such as expert designers, "have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment. This in turn, affects their abilities to remember, reason, and solve problems" (p. 19). Therefore, it should be considered of vital importance for technology educators to understand and explore the various strategies expert designers use to help them organize and conceptualize design ideas as they engage in the design process.

Patterns of design thought: Convergent and divergent thinking. A cognitive strategy of engineering design often employed to help frame the problem is to use a combination of convergent-divergent questioning. "*Convergent thinking* [is] where the questioner attempts to converge on and reveal 'facts.' Therefore, answers to converging questions are expected to . . . hold *truth value*, that is, to be verifiable. Deep reasoning questions are such questions" (Dym, Agogino, Ozgur, Frey, & Leifer, 2005, p. 105). However, engineering design thinking often takes a designer down a path of questioning that is not verifiable or does not contain *truth value*, but rather is based on unproven concepts. This is where divergent thinking becomes a critical component in the engineering design process. "Divergent inquiry takes place in the concept domain, where concepts or answers themselves do not have truth value, that is, they are not necessarily verifiable. This avenue is the design or synthesis model" (Dym, Agogino, Ozgur, Frey, & Leifer, 2005, p. 105). This iterative process of convergent and divergent thinking in engineering design is important for technology education to consider when integrating math and science into the design process. The development of excellent engineering designers will require more than students who can grab the right math formula and the appropriate science law for the engineering problem. Divergent thinking will also be an important skill, particularly to develop critical thinkers. A danger lies in the over emphasis on convergent thinking and the application of math and science that, in isolation of divergent thinking, may not generate good design and creative thinking.

Framing the problem. The iteration pattern seems to appear most often during the early steps in the engineering design process and especially the portion of the process often referred to as *framing the problem*. When introduced to an engineering problem, the engineer might begin by gathering as much information about the problem as possible. One technique might involve asking questions to *locate the frame* of the problem within which to work. The frame of the problem enables the engineer to focus on the relevant information required to solve the problem. Instead of looking for a solution that can fit multiple criteria, the engineer seeks to define a set criterion in which to work. This is a critical step to make the problem manageable and ensures that the solution will meet the desired outcome.

> Asking questions emerges as a beginning step of any design project or class in the *problem definition* phase. . . . No sooner has a client or professor defined a series of objectives for a designed artifact than the designers–whether in a real design studio or a classroom–want to know what the client really wants. What is a safe product? What do you mean by cheap? How do you define the best? Questioning is clearly an integral part of design. (Dym, Agogino, Ozgur, Frey, & Leifer, 2005, p. 104)

A protocol analysis study of engineering design students (Atman, Chimka, Bursic, & Nachtmann, 1999) identified that this *problem framing,* or as the study called it “problem scoping,” (p. 133) is critical to the success of the design. Atman, et al. discovered that the participants in the protocol study that used *problem scoping* techniques to gather a large amount of problem related data produced better design solutions than designers who did not use this method. The study also indicated that freshmen students new to engineering design often were trapped in the problem framing section of the design process. Cross (2004) found that such trapping resulted in a reduction of the overall effectiveness in using the engineering design process and lead to poor design solutions. Clearly, framing the problem accurately can help lead to a successful design. Likewise, having the ability to decipher when all relevant information has been obtained, and knowing when to move to the next step are both critical skills. Cross’s study identified these abilities as factors that separate novice from expert engineers.

One technique suggested for problem framing focused not only on the problem but also on the solution. Cross (2004) further identified that many expert designers use “solution conjectures” to allow themselves to not only frame the problem but also consider a possible solution early in the engineering design process. This solution conjecture method of problem-solution framing has often been credited as an effective method to fully explore the problem and solutions rapidly. This method of framing the problem is also known as the solution focused approach. Furthermore, Cross, referencing a Dorst and Cross study of creativity in design, found that many designers work in a co-evolution of solution and problem space to develop their designs. The problem space is where the search for the solution begins, starting conditions are identified, and goals are stated. This problem space creates a partial structure from which a solution space can be formed. The solution space structure begins to be developed as ideas are generated. This creative design process, like much of design is another iterative process that seeks to create a cohesive problem space and solution space (Cross, 2004).

Schön (1983) used the term "problem setting" (p. 40) to refer to framing the problem. He wrote, "Problem setting is a process in which, interactively, we *name* the things to which we will attend and *frame* the context in which we will attend to them" (p. 40). Schön emphasized the importance of problem setting and that designers often focus only on problem solving and thus, ignore problem setting. Schön also stated

> In real-world practice, problems do not present themselves to the practitioner as givens. They [problems] must be constructed from the materials of problematic situations which are puzzling, troubling, and uncertain. In order to convert a problematic situation to a problem, a practitioner must do a certain kind of work. He must make sense of an uncertain situation that initially makes no sense (1983, p. 40).

Experts in the field of engineering and those who study engineers have clearly identified the importance of framing the problem to provide direction for the engineer to proceed through the design process in order to lead to the success of the design. Cross's conclusions from his study of expertise in design indicated that the designer's ability to structure and formulate a design problem is a key element in design expertise strategies; moreover, the method of problem framing appears to be the best way to accomplish this task (Cross, 2004). These findings indicate that teaching students how to frame a problem will be a critical step for them to experience design successfully.

Approaches to problem solving within design. Kruger and Cross (2001) conducted a protocol study of nine expert industrial engineers who were given the same design challenge. This study identified four ways designers drive a design problem. These four design strategies are (a) problem driven, (b) information driven, (c) solution driven, and (d) knowledge driven. *Problem-driven* designers were found to focus closely on the problem assigned and used only the information and knowledge strictly needed to solve the problem. *Information-driven* designers sought to gather information from outside sources and then developed a solution based on this new information. *Solution-driven* designers focused on generating solutions with little time spent on defining the problem. Sometimes a solution-driven designer even reframed the problem to fit the solution created. Finally, a *knowledge-*

driven designer utilized his or her prior knowledge as the primary basis for developing a solution (Kruger & Cross, 2001).

Kruger and Cross (2001) were seeking to understand the relationship between cognitive style, design strategy, and design performance. Assessments of the design performances were conducted independently by a group of five Delft University of Technology faculty of Industrial Design Engineering. The assessment scoring categories were creativity, aesthetics, technical aspects, ergonomics, and business aspects.

The original assumptions of the researchers were that designers who used a problem-driven or information-driven approach were expected to produce few solutions but would generate a long list of design solution requirements (design criteria), and receive a low creativity score. Using the solution-driven design strategy was believed to produce many solutions, with few requirements identified, but produce a high creativity score and a high overall score on the design challenge. Finally, knowledge-driven expectations were defined by the researchers as providing few solutions, identifying few requirements, but producing a high creativity score and a low overall score. Kruger and Cross's research study produced mixed results, but did confirm most of their expectations. One exception was that problem-driven strategies performed much higher design results than expected. Problem-driven designers produced many solutions, received high scores on creativity, and produced good overall results. Another exception to note in their study was that solution-driven design did not produce the creativity results as expected (Kruger & Cross, 2001).

A scatter gram of participants' creativity scores was compared with their overall scores, and in general, the results revealed that creativity was a significant aspect of a good design. However, creativity does not necessarily mean good design. One participant scored high for creativity but lowest on overall quality of the design. These are important findings to consider as technology educators seek to teach creativity and design. Students should learn that a balance must be achieved with all aspects of defined design criteria.

Protocol studies of young industrial designers revealed that a student's ability to properly and quickly frame the problem is a critical skill (Cross, Christiaans, & Dorst, 1996). Possession of this skill allows the designers to rapidly move to developing solutions. These studies found that when some students used an information-driven strategy, they got focused on information gathering instead of generating design solutions. Certainly, it is easy to identify that a novice engineering designer can fall into the trap of becoming an information gatherer and resist working on the real problem. This trap has often been considered as a way of *buying time* or *stalling* from getting down to the business of designing (Welch & Lim, 2000).

The results of these research studies may provide valuable insights for developers of K-12 engineering and technology education pedagogy. Technology education's tradition of teaching the design processes has been predominantly linear in nature and problem-driven. Although the problem-driven approach proved to be the most successful method in the Kruger and Cross (2001) study, the other approaches to design are important to consider and should be presented as viable alternative methods to the design process.

In his studies, Omer Akin found that expert architects would often search for multiple creative solutions. He wrote, "What is interesting in these findings is that architects generated new solutions even when they already found satisfactory ones" (Akin, 2001, p. 8). Akin observed that architects often restructured the problem and launched into a search for an alternative design. Engineers are less likely to take this approach, because they are often not trained to develop creative solutions; rather, they are asked to find a solution that works in a timely, cost effective manner.

As technology education continues to seek the most effective strategies for teaching design and engineering design, educators must be careful to provide a variety of approaches to the design process and not limit students' exposure to just one method. Furthermore, providing a proper balance in design skill development is equally important. Recent advancements in design software can provide an ideal platform to teach design and implement cutting edge technologies, but a careful balance of instruction should be considered.

Learning CADD software. Computer Aided Drafting and Design (CADD) software is a powerful design tool, and like many emerging technologies, educators quickly implement the latest software to keep a curriculum program current with industry standards. A strong case can be made that honing CADD skills for a designer is not only helpful, it is essential to remain competitive in today's design industry. However, CADD software should not replace traditional design instruction nor should one assume that someone who masters CADD software is an expert designer. CADD software is one of a number of design tools in a designer's *tool box*. Some technology educators appear to consider

CADD software instruction synonymously with design instruction. Todd Kelley & Wicklein (2009) in a national status study of technology teacher's curricular focus on engineering design content found a strong emphasis on CADD instruction. A total of 226 high school teachers responded to the survey instrument. In the Engineering Design category, the highest-ranking individual item (measured by time per typical use) was *use of computer-aided design to construct technical drawings* with a mean score of 3.35 on a 5-point Likert scale. A special Likert scale conversion to time and frequency was provided to participants. The 3.35 mean score for this item equated to over half of a typical class period per day spent on teaching computer-aided design. In a national study of technology education, Sanders (2001) found similar results in that CADD was the most frequently taught high school technology education course category. The emphasis on CADD in technology education has been observed in other status studies (Dearing & Daugherty, 2004; Warner & Morford, 2004; Warner, Morford-Erli, Johnson, & Greiner, 2007). These results beg the question: If computer-aided design demands large amounts of instruction time and practice time, can it raid technology education instructors of critical time to teach other fundamentals of creativity and design experiences?

PROCEDURES FOR CREATIVE DESIGN

Creative design can be a mystery for the novice. One of the most common questions asked of creative people is, "Where do you get your ideas?" This is a genuine question, because any sufficiently creative idea seems like magic to the average person. Design education has to be predicated on the position that there are procedures that can be taught and learned to increase creativity in design.

Rosenman and Gero (1993) looked for commonalities in creative designs and identified four procedures that seemed to be operative in many creative processes. These commonalities seem to suggest the possibility of a set of procedures that once identified, might be able to be learned. The first procedure they identified was "combination" (p. 127). This procedure is simply taking useful features from one or more existing designs and putting them together in a novel configuration.

A second procedure was referred to as "mutation" (Rosenman & Gero, 1993, p. 128). This procedure is the modification of an existing design by modifying its parts systematically one by one to see if there are beneficial results or the process could be more random. The term *mutation* was borrowed from Darwin's concept of evolution, which operates through a series of mutations that are favorable to the evolution of a particular species. In Darwin's depiction of this process in nature there is a certain amount of randomness; however, in creative design the process is more directed and purposeful.

"Analogy" (Rosenman & Gero, 1993, p. 129) is a third procedure in creative design. This is the procedure of looking at one thing and seeing another. The creative step is accomplished by seeing how one thing is like or analogous to another. Tom Kelley (2005) stated that the design firm IDEO builds this step into their process by purposely studying an analogous example (i.e., something that is not the same as the problem they are working on but has some similar features).

Going back to "first principles" (Rosenman & Gero, 1993, p. 130) is a fourth procedure used in creative design. This is the process of trying to identify what the key ideas were in the beginning of any design challenge. Designers try to adopt a child-like naivety and look at a common problem as if they were seeing it for the first time.

A fifth procedure was later added to this list by Cross (2006) who referred to the procedure as "emergence" (p. 76). In this procedure, hidden or unidentified properties existing in a design are recognized. In some cases it may be a value added aspect that had not been originally seen. The term *emergence* came from the field of complexity science in which a novel, and often unanticipated form develops while a routine procedure is enacted. Mathematical models for emergent properties are useful in complexity science for unpredictable or chaotic events as diverse as weather patterns, traffic patterns, and earthquakes (Holland, 1999).

While there may be other favorite procedures that could be added to this list of combination, mutation, analogy, first principles, and emergence, these five can be fairly useful. The importance is, whatever the list, there are identifiable procedures to demystify the *magic* of creative design that open up the possibility of teaching and learning.

Four stages of creative problem solving. While the creative design process is often nebulous and ill-defined, it is helpful to have a loose structure in mind for how to attack any given design task.

Lawson (2005) suggested four stages in creative problem solving:

- Stage 1 is the *assimilation* of the nature of the task at hand by accumulating and analyzing information related to the problem.
- Stage 2 is conducting a *general study* to investigate the nature of the problem and possible means of solving it.
- Stage 3 is *development* and refinement of one or more tentative

solutions.

- Stage 4 is *communicating* one or more of the solutions to others, either inside or outside the design team.

Having these four stages in mind provides a way to add some systematic method to an elusive task.

DESIGN KNOWLEDGE AND SKILL DEVELOPMENT

The domains of design knowledge are manifested in many forms. These domains include images (e.g., information design, graphic design, typography, web design, and photography); objects (e.g., product design, industrial design, auto design, furniture, appliances, and fashion); places (e.g., architecture, landscape, interiors, urban planning, set design, and exhibit design); and experiences (e.g., interactive toys, games, video games, theme parks, events, and festivals).

Many designers are now incorporating all of these forms of design and several other skills into *system design* that blends marketing, design, and manufacturing into a single approach to product development (Durst & Prokopoff, 2009). Nike, for example, does an annual run called "The Human Race" in which people from around the world can participate wherever they are because a device in the Nike + shoe calculates their time, pace, distance, etc. and transmits it through their iPod, iPhone, or special sports wristband to the race officials (http://nikerunning.nike.com/nikeos/p/nikeplus/en_US/humanrace). In this way, someone can either be in one of the cities around the world where people congregate to run in the traditional manner, or they can run on any street, sidewalk, or path wherever they are and still have their data entered into the race statistics.

Skill development in design includes many aspects. These aspects include ideation, research, criteria development, generating potential solutions, visualization, prototyping, presentation, selection, production, implementation, and evaluation (Aspelund, 2010).

For school purposes these aspects are often presented in several steps. *Ideation* is the ability to identify and clarify the intent of the problem to be solved or goal to be met. Designers try to avoid solving the wrong problem. Along with ideation, designers *research* the problem and gather information on how similar problems were solved. In this process the *criteria* or specification for a successful solution are developed.

Students then generate several potential solutions and make them available to others through *visualization*. Sketching and drawing are the most common ways to work out potential solutions. It is important that this work be done in some visual form so that other individuals can understand what is going on in the designer's mind.

Modeling and prototyping are the next major steps in generating a design. Students must create models (formative representations) and prototypes (full scale, functional representations) along the way to work out structural or material needs and try out the ideas they have only visualized so far. The ideas are refined and tested in this process. Usually at some set point in time, the most viable potential solution to the problem must be put into a form of a *presentation* that can be shared with other people for review and approval. This process requires the student to produce a finished mockup of the most viable design and use verbal and visual communication skills to present and explain the created design. For designers, this presentation might be provided to clients.

The approved design must then be engineered for *production*. The specification and preparations for effectively manufacturing or constructing, the design needs to be translated into useful forms. Production is followed by distribution and dissemination of the product. The customer or user *implements* the product and provides valuable *evaluation* of the success of the design.

Background knowledge and skills. Designers need considerable background knowledge of material science, structural requirements, user needs, contextual appropriateness, environmental impact, social implications, economic feasibility, sustainability, and a variety of other factors. Designs do not exist in a vacuum.

Philip (2004) indicated that the background knowledge needed includes an awareness of the expectations of the client, the needs of the users, the specifications of the design brief, the limitations of material and production, and the design traditions related to the problem. Ambrose and Harris (2009) noted that graphic designers need to have a thorough knowledge of typefaces, paper qualities, color reproduction, design standards, and reproduction methods. Morris (2009) wrote that product designers should know the properties of materials, limitations and potential of production methods, ergonomics, disassembly, and a host of other knowledge based expectations.

In addition to knowledge, novice designers need to develop the requisite conceptual, procedural, drawing, modeling, and presentation skills to successfully carry their design to completion. The challenge of innovation in design is to move beyond the initial creative spark and do the hard work of translating the idea into a tangible, feasible, useable, and compelling design.

Sketching, mechanical drawing, and visualization skills. Sketching is an integral part of the design process. It is the way to get ideas out in the open to be shared and developed. Unfortunately, sketching is sometimes confused with drawing and novices may be concerned, because they believe they do not know how to draw (Lawson, 2005).

There are many types of sketching in design, ranging from quick thumbnails (small drawings) to concept sketches and storyboards. The aesthetic quality of the drawings is not as important as the ability to clearly and convincingly communicate an idea visually. The important thing is to communicate an idea in a tangible form so someone else can understand it and possibly offer additional input.

Designers often have a sketchbook on hand, because it is such a standard part of their creative process. If they do not have a sketchbook handy designers will draw on anything available, including napkins.

Roam (2008) argued that anyone could use visual thinking to work through complex problems. His book, *The Back of the Napkin*, was designed to get non-visual business people to utilize drawings to convey to each other visual, quantitative, qualitative, procedural, spatial, temporal, and explanatory information and ideas.

Designers use a variety of drawing approaches depending on the task at hand. Doodles or quick sketches are used to work out ideas and sometimes just to entertain one's own mind. Presentation drawings are at the other end of the spectrum. Skilled artists prepare these drawings carefully to inspire and impress the viewer with a design proposal.

Conceptual modeling. Conceptual models are employed by designers to think, problem solve, and communicate internal thought processes. They are quick and often paper representations in three-dimensional form to capture some aspect of a design. These models offer another way for a visual person to think. In graphic design the conceptual model might be a rough mock-up, in product design it might be made of clay, and in environment design it might be a paperboard model.

For many designers there is a distinct difference between modeling and prototyping, although design literature has many examples of these terms being used interchangeably. Prototyping is considered to be the making of an example of the design that is full size, using the materials and processes intended for the production version, which is fully functional (Hutchinson & Karsnitz, 1993). In contrast, Tom Kelley (2005) said that, at the design firm IDEO, prototyping is a way to experiment with an idea. Modeling of this sort is an opportunity to try out ideas and test assumptions about materials, structures, and the design in general. These models are often done rapidly with inexpensive materials to get a sense of how an idea is working. It is possible to have a design that looks good in sketch form but is not able to be executed in reality. Modeling helps reveal such problems.

Prototyping. A prototype is a concrete, tangible representation of a design. Warfel (2009) stated that prototypes act as a common visual language for communication and collaboration among various stakeholders in the design process.

According to Warfel (2009), prototypes are generative in helping to produce ideas and communicative in letting you experience a design. They reduce misinterpretation; save time, effort, and money; and reduce waste. Prototypes also perform the different functions of sharing communication, working through a design, selling your idea internally, testing usability, and gauging technical feasibility and value.

Moving students beyond conceptual fixedness. There are several points in the creative design process where there is a danger of making a miss-step, because of a thinking behavior known as conceptual or functional fixedness. Karl Duncker (1945) was the first to identify the concept of *fixedness* within the field of Gestalt psychology. He described functional fixedness as being a mental block against using an object in a new way that is required to solve a problem.

Conceptual fixedness can occur in several ways within a design activity. In the initial ideation stage, there is a danger of focusing on the wrong problem. Students must learn to identify and clarify the problem to be solved and be open to the idea that the real problem might not be correctly identified in the way it is initially presented. A second common place for conceptual fixedness to strike is when designers try to generate a variety of solutions to a design challenge. Cross (2006) emphasized the importance of a designer developing several initial, conjectured solutions to a problem. Novice designers will have a tendency to latch on to the first idea they come upon or generate a small set of possible solutions that do not yet go beyond easily generated, but often, stereotypical solutions.

The success of a design is not determined solely by the expert opinion of the designer. The efficacy of a design is determined by how well it works in the real-world setting. There is a common danger for designers to be overly charmed by some cleverness or quality of their design that none-the-less does not produce the required results. Novice designers are too often seduced by ideas that work well within the context of fellow designers without sufficiently considering how the design will work for actual clients or users (Berkun, 2007).

In a research study within technology education, Kelley, Brenner, and Pieper (2010) conducted *think aloud* observational protocols of *Project Lead the Way* (PLTW) and *Engineering Projects in Community Service (EPICS High)* students as they worked through an ill-defined problem. The results of this study revealed that both groups of students became fixated upon a picture that was included in an ill-defined problem statement. The ill-defined problem required students to design a playground for a new elementary school. A picture of a newly constructed school was added to the problem statement to provide a general context to the statement. There was no reference in the statement indicating that this picture was of the actual school in need of a playground. Seven of the twelve participants in the study became fixated on the picture at some point in their verbal protocol and continued to reference the picture even after researchers indicated that the picture was just added for context. The results of the Kelley et al. study also indicated that students often use a strategy to solve a problem by looking for clues within the student handout.

Technology educators should help students to move beyond these mental barriers by being aware of where and how fixedness can appear in the design process. They should become aware of this potential problem when they draft design problem statements, provide handouts, and show student examples of design solutions to design briefs. Introducing design solution examples or exemplars to students too early in the design process can generate *fixation*, and thus, limit students' creative design thinking. Technology educators teaching design through real world ill-defined problems should, therefore, help students to develop strategies to properly frame a design problem so it can be solved without limiting their creative thinking.

Achieving "flow." Creative activity is intrinsically rewarding. Creative people are often motivated and rewarded by the simple pleasure of creating something new and functional. *Flow* is the mental state described by Csikszentmihalyi (2008) in which a person is fully immersed in what he or she is doing. A feeling of energized focus, full involvement, and successful performance transcends the activity. According to Csikszentmihalyi, flow is completely focused single-minded immersion that is the ultimate state in harnessing the emotions in performing and learning. In flow the emotions are not just contained and channeled, but positively energized, and aligned with the task at hand. Flow is a feeling of spontaneous joy or rapture while performing a task.

Csikszentmihalyi (2008) identified factors accompanying an experience of flow, including

- Clear goals that are challenging but attainable and align with one's abilities.
- A high degree of concentration on a focused activity.
- The merging of action and awareness and a loss of self-consciousness.
- The distortion of the sense of time.
- Direct and immediate feedback so that successes and failures in the course of the activity are apparent and adjusted for.
- A sense of personal control over the situation or activity.
- The activity is intrinsically rewarding and seems effortless.

People become absorbed in their activity, and their focus of awareness is narrowed down to the activity itself. These factors explain why people are attracted to creative enterprises and seek them out in life.

Applying knowledge and skills toward creativity in technology education. It is appropriate for leaders in the field of technology education to make a careful self-examination of what the field has become in practice regarding creativity and design. All too often, technology educators have taken a pedagogical approach to emphasize one phase of the design process or one element of creativity. For example, the emphasis on CADD within technology education illustrates how often technology educators become locked into one phase of the design process and focus on a high tech tool (Dearing & Daugherty, 2004; Kelley & Wicklein, 2009; Warner & Morford, 2004; Warner, Morford-Erli, Johnson, & Greiner, 2007). However, this phenomenon does not just happen with high tech tools; some technology teachers may overemphasize sketching, brainstorming, or other stages of the design process.

As the field of technology education considers a move to engineering design as a focus, tough choices regarding the scope of curriculum content will affect how creativity and design are taught. Educators should consider the top five engineering design concepts identified in Dearing and Daugherty's study (2004). The top five ranked concepts identified were

- interpersonal skills (i.e., teamwork, group skills, attitude, and work ethic);
- ability to communicate ideas (e.g., verbally, physically, and visually);
- working within constraints/parameters;
- experience in brainstorming and generating ideas; and
- product design assessment (i.e., performance of intended function). (p. 9)

These student outcomes for an engineering design approach to technology education can neither be achieved through a hard-line engineering science approach of statics and dynamics courses nor by teaching sequential CADD courses. A better approach to achieving these outcomes would come through a holistic approach to creativity and design that provides experiences in all phases of the design process.

Often, the design process has been taught in technology education as a problem solving strategy (McCade, 1990). It is critical for the field of technology education to consider the characteristics and outcomes it would like to develop in students as designers: whether creative problem solvers who can generate multiple solutions, or problem solvers who can quickly locate the most efficient and cost effective solution. Certainly, a case can be made for both types of problem solvers, quite possibly a blend of experiences in problem solving would be appropriate for the field to consider as it makes a shift towards engineering design.

CONCLUSIONS AND SUMMARY

The authors of this chapter focused on domain specific knowledge and skills that influence an individual's creative expression through design. The chapter began with an exploration of the importance of knowledge and skills that foster creativity through design. Review of results from research studies of expert and novice designers provided insight into identifying the necessary knowledge and skill sets to become a successful and creative designer. The authors of the chapter sought to provide readers with a synthesis of current design and creative strategies used by practicing designers and educators of design. Throughout each section of the chapter, the authors addressed how the specific concept, knowledge, or skill examined might be introduced in technology education classrooms. The chapter culminates with a discussion locating the appropriate levels of knowledge and skills necessary to prepare technologically literate individuals to function in a global society.

In closing, the authors present a strong message to the technology education community: As the field continues to move to an engineering design focus, it is critical that technology educators locate a proper balance in the necessary design knowledge and skills that also provide opportunities to foster creative thinking. Technology education students not only need engineering design skills to function in a global society but also must be creative designers and problem solvers. Consider the words from the National Center on Education and the Economy (NCEE) "Creativity, innovation, and flexibility will not be the special province of an elite. It will be demanded of virtually everyone who is making a decent living, from graphic artist to assembly line worker, from insurance brokers to home builders" (NCEE, 2007, p. 25). The report goes on to indicate that the only way today's American engineers will be competitive in a global market will be through their ability to produce creative work. Technology educators should assess current design teaching practices to determine if a proper balance of design knowledge and skills is achieved to prepare creative technologically literate individuals.

REFLECTIVE QUESTIONS

1. What changes could be made to contemporary technology and engineering education curriculums so as to provide students with enriching experiences and instruction in creativity and design?
2. How might technology educators best address the top engineering design concepts identified in Dearing and Daugherty's study (2004)?
3. What would be appropriate design-based problems/activities to be studied in technology education to address the top engineering design concepts?
4. What design knowledge or strategies that were discussed in this chapter are currently missing from technology education programs?
5. How might implementing design strategies enhance a technology education classroom?

REFERENCES

Akin, O. (2001). Variants in design cognition. In C. Eastman, M. McCracken, & W. Newstetter (Eds.), Design *knowing and learning: Cognition in design education* (pp. 105-124). Amsterdam: Elsevier.

Ambrose, G. & Harris, P. (2009). *The fundamentals of graphic design*. Lausanne, Switzerland: AVA.

Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshmen and senior engineering design processes. *Design Studies, 20*(2), 131-152.

Amabile, T. M. (1996). *Creativity in context*. Boulder, CO: Westview Press.

Aspelund, K. (2010). *The design process*. New York: Fairchild.

Berkun, S. (2007). *The myths of innovation*. New York: O'Reilly Media.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: The National Academies Press.

Cross, N. (2004). Expertise in design: An overview. *Design Studies, 25*(5), 427-441.

Cross, N. (2006). *Designerly way of knowing*. London: Springer-Verlag.

Cross, N., Christiaans, H., & Dorst, K. (Eds.). (1996). Analysing design activity. West Sussex, England: Wiley.

Csikszentmihalyi, M. (2008). *Flow: The psychology of optimal experience.* New York: Harper.

Dearing, B. M., & Daugherty, M. K. (2004). Delivering engineering content in technology education. *The Technology Teacher, 64*(3), 8-11.

Duncker, K. (1945). On problem solving. *Psychological Monographs, 58*(5, Whole No. 270).

Durst, F. & Prokopoff, I. (2009, Winter). Designing Systems at Scale. *Rotman Magazine*, 53-56.

Dym, C. L., Agogino, A. M., Ozgur, E., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 103-120.

Edwards, B. (1999). *The new drawing on the right side of the brain*. New York: Jeremy P. Tarcher/Putnam.

Gardner, H. (1983). *Frames of Mind: The theory of multiple intelligences*, New York: Basic Books.

Greenfield, S. (Ed.). (1996). *The human mind explained*. New York: Henry Holt.

Hailey, C. E., Erickson, T., Becker, K., & Thomas, T. (2005). National center for engineering and technology education. *The Technology Teacher, 64*(5), 23-26.

Halfin, H. H. (1973). *Technology: A process approach*. Dissertation Abstracts, *11*(1), 1111A.

Hill, R. B. (1997). The design of an instrument to assess problem solving activities in technology education. *Journal of Technology Education, 9*(1), 31-46.

Hill, R. B. & Wicklein, R. C. (1999). A factor analysis of primary mental processes for technical problem solving. *Journal of Industrial Teacher Education, 36*(2), 83-100.

Holland, J. (1999). *Emergence: From chaos to order*. New York: Basic Books.

Hutchinson, J. & Karsnitz, J. (1993). *Design & problem solving in technology.* Albany, NY: Delmar.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

Johnson, S. D. (1992). A framework for technology education curricula which emphasizes intellectual processes. *Journal of Technology Education, 3*(2), 26-36.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63-85.

Kelley, T. [Tom] (2001). *Art of innovation*. New York: Doubleday.

Kelley, T. [Tom] (2005). *The ten faces of innovation*. New York: Broadway Business.

Kelley, T. [Todd] (2008). Cognitive processes of students participating in two approaches to technology education. *Journal of Technology Education*, *19*(2), 50-64.

Kelley, T. [Todd] & Wicklein, R. C. (2009). Examination of engineering design curriculum content in secondary technology education. *Journal of Industrial Teacher Education*, *46*(1), 7-31.

Kelley, T. [Todd], Brenner, D., & Pieper, J. (2010). Two approaches to engineering design: Observations in sTEm education. *Journal of sTEm Teacher Education*, *47*(2), 5-40.

Kruger, C. & Cross, N. (2001). Model Cognitive Strategies in Creative Design. In J. Gero & M. Maher (Eds.), *Computational and cognitive model of creative design V* (pp. 205-226). University of Sydney, Australia.

Lawson, B. (2005). *How designers think* (4th ed.). London: Architectural Press.

Lewis, T. (2005). Coming to terms with engineering design as content. *Journal of Technology Education, 16*(2), 37-54.

McCade, J. (1990). Problem solving: Much more than just design. *Journal of Technology Education, 2*(1), 1-13.

Moggridge, B. (2007). *Designing Interactions*. Boston: MIT Press.

Morris, R. (2009). *The fundamentals of product design*. Lausanne, Switzerland: AVA.

National Center on Education and the Economy. (2006). *Tough choices or tough times: The report on the new commission on the skills of the American workforce.* Hoboken, NJ: Jossey-Bass.

Norden, J. (2007). *Understanding the brain, Parts 1-3*. Chantilly, VA: The Teaching Company.

Roam, D. (2008). *The back of the napkin.* New York: Penguin Group.

Roberts, P. (1994). The place of design in technology education. In D. Layton (Ed.), *Innovations in science and technology education* (Vol. 5, pp. 171-179). Paris: UNESCO.

Rosenman, M. A. & Gero, J. S. (1993) *Creativity in design using a prototype approach*. In J. S. Gero and M. L. Maher (Eds.). *Modeling creativity and knowledge-based creative design* (pp. 111-138). Hillsdale, NJ: Lawrence Erlbaum Associates.

Sanders, M. (2001). New paradigm or old wine? The status of technology education practice in the United States. *Journal of Technology education, 12*(2), 35-55.

Schön, D. A. (1983). *The reflective practitioner*. New York: Basic Books.

Shedroff, N. (2001). *Experience design*. Indianapolis, IN: Que.

Sternberg, R. J. (1994). Intelligence. In R. J. Sternberg (Ed.), *Thinking and problem solving* (2nd ed., pp. 263-288). San Diego: Academic Press.

Sternberg, R. J. (1988). *The triarchic mind: A theory of human intelligence*. New York: Viking.

Warner, S. A. & Morford, L. L. (2004). The status of design in technology teacher education in the United States. *Journal of Technology Education, 15*(2), 33-45.

Warner, S. A., Morford-Erli, L. L., Johnson, C. W., & Greiner, S. W. (2007). Identifying the paradigm of design faculty in undergraduate technology teacher education in the United States. *Journal of Technology Education*, *18*(2), 68-87.

Welch, M. & Lim, H. (2000). The strategic thinking of novice designers' discontinuity between theory and practice. *Journal of Technology Studies, 26*(2), 34-44.

Wicklein, R. C. (2006). Five good reasons for engineering design as the focus for technology education. *The Technology Teacher*, *65*(7), 25-29.

Wicklein, R. C. & Rojewski, J. W. (1999). Toward a unified curriculum framework for technology education. *Journal of Industrial Teacher Education, 36(*4), 38-56.

Physical Environments for Creativity and Design

Chapter 8

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Think of the last time you were in an elementary school. What did the classroom look like? You probably saw bright colors, reading areas, posters, student work, and resources throughout the room. If you travel to a middle school or high school and walk down the halls what do you see? Most likely the classroom environment changed drastically. Colors disappear or become muted and desks are arranged into rows, but why? As students progress through the grades it seems that fewer teachers and administrators put much thought into how the classroom environment can affect students' learning, engagement, and creative output.

Research (Gallagher, 1993; Chism, 2002) indicated that the physical environment in which young people are taught and learn can significantly influence not only their behavior but also their creative output. Creativity and design are the foundation on which technology education is taught and learned (International Technology Education Association [ITEA], 2000; ITEA, 1996). Though technology education teachers expect their students to be creative, support is needed to help enhance the physical environment to stimulate that creativity.

As will become evident to the reader, the classroom atmosphere has an extremely important impact on student learning and success. This chapter focuses on the importance of the relationship of that physical environment to students' creative output. How the physical environment influences students, a broad history of the development of the technology education classroom, and the nature of contemporary technology education facilities will be discussed. The heart of the chapter is devoted to an explanation of the eight major physical environmental variables, which can affect the creative potential in all classrooms and especially the technology education facility.

IMPORTANCE OF THE PHYSICAL ENVIRONMENT

The physical surrounding and environment affects people psychologically in different ways. Gallagher (1993) explained how our surroundings shape our thoughts, emotions, and actions. In her book she stated,

> Throughout history, people of all cultures have assumed that environment influences behavior. Now modern science is confirming that our actions, thoughts, and feelings are indeed shaped not just by our genes and neurochemistry, history, and relationships, but also our surroundings. (p. 12)

Therefore, our surroundings can have a great impact socially. Think about experiences you have everyday and how you change depending on your surroundings. Rob Walker of the Centre for Applied Research in Education at the University of East Anglia in England described the following example:

> We know that we avoid looking directly at people in a crowded lift or a rush-hour tube train and that we calculate how close to sit to others in a public space, a cinema or on a beach. We tend not to be specific about these things, but we know when we feel comfortable or uneasy in the presence of others. Classrooms are no different. (2007, p. 25)

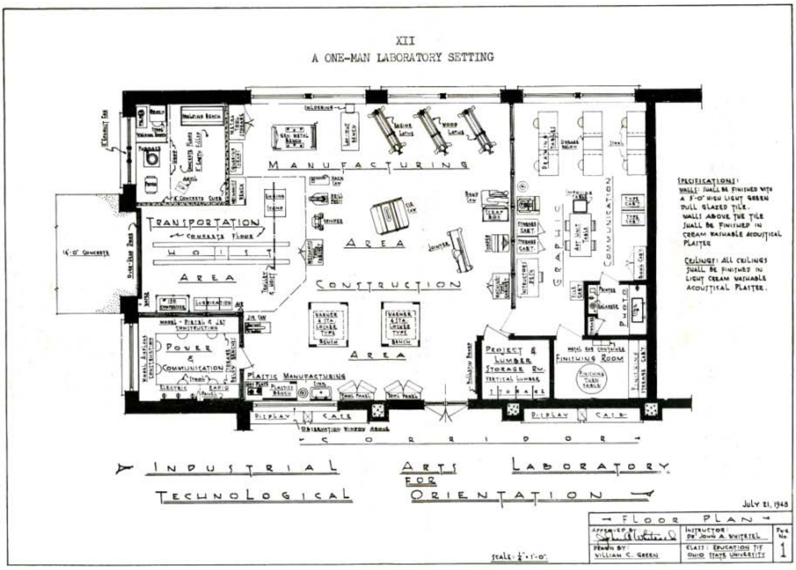
Many different aspects of the classroom environment affect students. Graetz and Goliber (2002) noted, “that the physical classroom environment can facilitate or inhibit learning, both directly (through noise, crowding) and symbolically (as when students attribute poor classroom design and maintenance to lack of respect on the part of the institution)” (p. 15). Teachers prepare their curriculum and lessons diligently and with care, they should do the same with the classroom environment. If teachers spend time on their environment, students will have greater success expressing their creative capabilities, especially in the technology education classroom.

According to Ekvall, "the accumulated body of research on climate and organizations undoubtedly indicates that climate makes a difference in creativity" (as cited in Peterson & Harrison, 2005, p. 9). Historically, technology education teachers have known of the importance of the physical environment toward teaching and learning. This understanding is evident within the work of many of the educators who laid the foundations of technology education. Individuals such as Pestalozzi, Froebel, Salomon (Nelson, 1981; Herschbach, 2009), Woodward (Wright, 1981; Herschbach, 2009), Bennett (Smith, 1981; Herschbach, 2009), and others would broadly address the importance of physical space and place toward the acts of teaching and learning. The importance of the physical environment continued as manual training changed over to industrial arts.

Sanders'(2001) comparison study of the programs and practices of industrial arts and technology education found that the most common course categories for industrial arts involved wood, metal, and drafting classes. As a result, industrial arts teachers had to arrange their classroom facilities to accommodate the varying needs of those three areas of the curricula (Moon, 1975).

The industrial arts learning environment continued to evolve with the curriculum as technology became increasingly complex. This connection is evident in a program development proposal that was led by William E. Warner. In the proposal, Warner stated that "equipment and facilities must echo the principal elements of the technology; its development and uses of power, its transportation, its construction, including housing and home furnishings, its communication even including the use of such specialized techniques as radar, and its basic types of manufacture" (Warner, 1953, p. 6). A floor plan for a model industrial arts laboratory to address a technological orientation, as proposed by Warner and his graduate students, can be seen in Figure 1 (next page). When industrial arts transitioned toward technology education, especially after the introduction of *Standards for Technological Literacy* (*SfTL*; ITEA, 2000), the curricula changed to become a broad study of technology through more creative problem-solving projects.

Figure 1. A floor plan for a proposed industrial arts laboratory to support technological orientation.



Source: "The Industrial Arts Curriculum: Development of a Program to Reflect American Technology" by W. E. Warner [with Gary, J. E., Gerbracht, C. J., Gilbert, H. G., Lisack, J. P., Kleintjes, P. L., and Phillips, K.] (1953) [Proposal], p. 62. Copyright 1953 by Epsilon Pi Tau.

With the implementation of these problem-solving activities it is evident that the classroom environment should be reevaluated to aid in the creative process that technology education students explore everyday. In Doyle's (1991) doctoral research his goal was to "identify, describe, and verify physical facility factors that affect technological problem solving activities in secondary technology education programs" (p. 8). Through his research of literature, teachers, and inventors he identified 74 factors that influence students in the technology education classroom. Doyle (1991) stated that "the environment for defining technological problems, generating or developing creative ideas for technological problem-solving, or implementing technological solutions require resources that are seldom found in most general public school libraries, classrooms, or technology education laboratories" (p. 130). Therefore, updating technology education facilities to foster creativity and problem solving should be as important as lesson planning and curriculum writing. With the constant state of technological change one could wonder what the characteristics of an ideal technology education facility would be. There are many considerations toward environmental characteristics that can create a beehive of creativity in the technology education classroom/lab. The first step in creating that facility is to focus on curricula.

THE TECHNOLOGY EDUCATION FACILITY

Many technology education programs vary in their curricular focus. Types of program focus include engineering and design, exploring technology, computers, vocational and technical skills, and career training. One approach for a technology education program to embrace creativity and design would be to have the curriculum and classroom/lab facility organized around addressing *SfTL* (ITEA, 2000). These standards assist in the development of a new or upgraded facility by acting as a philosophical foundation on which the program will be taught.

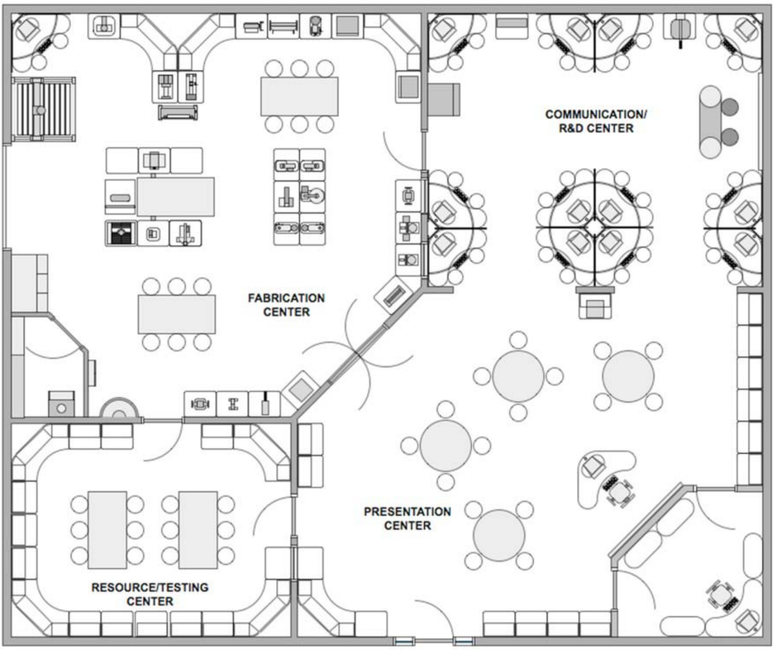
With the *SfTL* as a foundation for designing the organization and makeup of the technology education facility, classroom creativity will be enhanced through the change from the traditional shop to a design-based classroom. According to Daugherty, Klenke, and Neden (2008), the essential elements proposed for the modern technology education laboratory should include

- State-of-the-art presentation center to include delivery systems, projections systems and Smartboard technology.
- Multipurpose computer platforms to allow for a variety of computer applications including 3-D computer-aided design, desktop publishing, CNC systems and other specialized computer software.
- Flexible fabrication center that promotes portability and age-appropriate equipment and tooling usage.
- Mobile supply and material platforms that support invention, innovation and testing.

- Multipurpose workstations that provide convenient work centers for projects and activities.
- Supply and equipment storage as well as appropriate safety equipment. (p. 22)

A floor plan for a standards-based technology education laboratory, as proposed by Daugherty, Klenke, and Neden, can be seen in Figure 2.

Figure 2. The floor plan for a standards-based technology education laboratory.



Source: "Creating Standards-Based Technology Education Facilities" by M. Daugherty, A. Klenke, and M. Neden (2008), *The Technology Teacher*, *68*, p. 23. Copyright 2008 by the International Technology Education Association.

Overall, technology education facilities should be created to be flexible, learning-focused, safe, and accessible. Through the implementation of the essential elements, the technology education facility will be a step closer to facilitating creativity and standing up to the test of technological change. The next step towards facilitating the creative classroom is to recognize the environmental variables that affect students and how they can be used to aid in facilitating the creative learning environment.

Environmental Variables

There are, undoubtedly, a limitless number of environmental variables within a given classroom or laboratory which influence the creative potential of students. Warner and Myers (2010) identified from the literature eight broad categories into which most of these environmental variables would fit. These categories included lighting, color, decorations, furniture, resources, sensory variables, space configurations, and class size. The following sections summarize why these variables are important and how they affect the classroom and students.

Lighting. The vision system provides a physically capable human with a vast amount of information about what is happening in the surrounding environment. According to Hyerle (2000), "Research approximates that between 80 and 90 percent of the information received by the brain is through the eyes" (p. 48). Such a profound dependence on input from this one sense has ramifications toward how people develop their perceptions of the world and how they learn. Dondis (1973) observed that

> The first learning experience of a child is through tactile awareness. In addition to this 'hands-on' knowledge, recognition includes smelling, hearing, and tasting in a rich contact with the environment. These senses are quickly augmented and superseded by the iconic—the ability to see, to recognize and understand environmental and emotional forces visually. From nearly our first experience of the world, we organize our needs and pleasures, preferences and fears, with great dependence on what we see. Or what we want to see. But this description is only the tip of the iceberg and in no way measures the power and importance the visual sense exerts on our lives. We accept it without realizing that it can be improved just in the basic process of observation or extended into an incomparable tool of human communication. We accept seeing as we experience it—effortlessly. (p. 1)

According to Graetz and Goliber (2002) there is "an ongoing debate in environmental psychology pertaining to the merits of full spectrum or daylight fluorescent lamps versus the more common cool white fluorescent lamp" (p. 16). However, based on their review of research on this subject the authors would later summarize their findings by stating, "the optimal choice for collaborative classrooms may be normal intensity, full-spectrum or daylight fluorescent lighting" (p. 17).

The most basic lighting issue, and the one easiest to solve is general illumination level. Poor lighting, primarily the absence of sufficient illumination with or without attendant glare, is arguably the greatest environmental hindrance to learning. The overall goal is soft, diffuse light without glare. Another important goal is providing light "designed" to support a range of activities with different types, orientations, and levels of light. The small number of lighting options in a given context may limit opportunities for creative work. Painters, for example, generally prefer north facing, sky lit studios, because that type of daylight is nearly without shadow and, with proper positioning of equipment, glare free.

The creative process does not require perfect conditions, as history shows in the life stories of artists such as Georgia O'Keeffe ("Georgia O'Keeffe," 2002), Frida Kahlo ("Frida Kahlo," 2002), and Andy Warhol ("Andy Warhol," 2002). However, where it is possible to enhance conditions, it is desirable. A sufficient quantity of light is not enough. The quality of light matters as well. A single level of light in a room renders objects in a flattened, abstracted way. Variations of light level and direction at the perimeter of a space will conversely enhance the special qualities of the different objects and people that are the subject of attention. Different light levels can be used to create different zones of activity in which one activity is more favored, or rather supported by the resulting character of the light (Madsen, n.d.; Osterhaus, n.d.). A creative student can therefore seek out a space that suits his or her particular agenda, whether that space is selected consciously or unconsciously.

Color. Color has meaning. While there is, has been, and probably always will be debate about what particular colors arouse in the viewer, there are nonetheless associations that indicate an underlying order for color response (Birren, 2003; Albers, 1975). There is no truly neutral color. Paint manufacturers typically have a broad range of "white" paints, normally categorized as "off-white." Studies of landscape paintings show consistency in positive preferences for particular greens and blues, and such are then connected to evolutionary advantages in terms of associations with environments that support survival, due to the presence of vegetation, water, and bright, non-threatening skies. These "environmental" colors are, in varying degrees of saturation, often used in schools generally, and classrooms in particular. More saturated colors tend to be used with younger students, and so-called "refined" colors, (i.e., some reduction of saturation and value) are sometimes used in environments for older students.

Use of a single color for all walls of classrooms creates a monotone that suggests there is only one activity that can take place at a time. However, teaching in a creative environment inevitably involves not only full-class activity, but also individual, team, and small group processes.

As variation in light brings vitality to the teaching environment, so does variation in color. Use of an "accent" color on one wall can identify a "teaching wall" where the teacher may stand for talks and demonstrations, the location of the *interactive white board*, and an area for displaying projects. While classroom environments need flexibility, specific categories of activities that are identifiable in advance with specific subject areas can be reflected in the physical planning of the space, naturally including color.

As a licensed, practicing architect co-author Milton Shinberg has noted that the energy level for students can be manipulated in a school by increasing the intensity of color in the highest movement areas (e.g., stairways) and then stepping down the color intensity in hallways, and providing mild saturated colors in classrooms to calm the students. The higher saturated colors stimulate movement in the passageways while less saturated hues enable focus on the teacher/leader inside the classroom. As an example of how this dynamic use of color can work, in 1997 Milton's firm of Shinberg.Levinas Architects used colors in the large stairways, hallways, and classrooms to manipulate the energy levels of highly distractible students in their design of the Maya Angelou Public Charter School in Washington, D.C.. As reported by teachers, this color scheme worked exactly as intended.

Pytel (2006) described the potential effects that different colors have on students in the school environment (see Figure 3, next page). Note that green inspires creativity while other colors may add excitement or a calming effect.

Figure 3. How Colors Affect Student Perceptions and Behaviors

The Colors of the Classroom

Pale yellow/almond
• Best colors for not irritating anyone
• Good general color for school hallways
Light pink/rose
• Very soothing
• Suitable for a room where the activity is high
Green
• Creativity…is inspired by the color green
• Green is a great color for an art room
• An excellent choice for a creative writing center
Blue
• The color of academics
• Best color for a science or math room
• Light blue is a good overall classroom color… it is calming
Orange, yellow and red
• Bright yellow excites the brain and body
• The color orange seems to agitate

Note. Adapted from “Color and Learning: How does Color Affect Our Thinking and Feeling?” by B. Pytel (2006), *Educational Issues @ Suite 101*, accessed at http://www.suite101.com/content/color-and-learning-a3246. Copyright 2006 by Barbra Pytel.

DISPLAY OF STUDENT ACHIEVEMENTS AND RESEARCH

Creativity is promoted by the excitement engendered by exchange about good work and ideas. While that happens in verbal exchange, physical display of good work is also part of that cultural environment. Making the work visible and attractive can likewise encourage inspiration and some creative competitiveness. Most students will naturally want to have their work admired. Putting work on display shows that the teacher values the work and can strengthen student teacher relationships. According to Boynton and Boynton (2005), a teacher should remember

> The displayed work does not have to be perfect and should show a significant cross section of the students you have in your class. Putting the work of students who have a history of low achievement up on a bulletin board often helps to build their self-esteem and pride and encourages them to do better work in the future. (p. 16)

A display can be more than a surface with pins to hang images and papers. It can be a dynamic system of images that change regularly. Students can have "their day" when the work they have invested in is realized and shared, within their class or more broadly by use of screen displays. The display can be interactive and invite participation in research. As an example, a touch-screen display can ask questions and provide a place to record answers, both regarding preference or to participate in testing a hypothesis. Whereas, achievement may be the main course, display can be dessert and an inducement toward experimenting on new dishes.

Furniture. Learning is focus. Discomfort is distraction. Cornell (2002) described furniture as "both tool and environment" (p. 33). Cornell elaborated on the many aspects of these dual functions by noting

> Most furniture design focuses on functional need, such as flexibility, mobility, and wire management. It focuses on helping the user achieve a goal, be it relaxation, entertainment, education, or work. In a user-centered approach, functionality is just one of at least four dimensions to consider. Another design objective is comfort, safety, and health. The design should maintain if not promote well-being and quality of life. No design should be harmful. A third dimension is usability. The intended purpose and operation should be obvious to all users, hopefully with little or no training. The intention is to prevent accidents and optimize use. And fourth, the design should have psychological appeal. The user should feel motivated to use the design over and over again.
>
> Unlike Maslow's, this is not a hierarchy of needs. The dimensions are not additive but multiplicative—poor performance on one undermines the performance of the overall system. Furniture must address all four simultaneously or the efficacy of the design is in question. (p. 35)

The chair is the one piece of school furniture that clearly requires the full measure of the design dimensions discussed by Cornell (2002).

It is said that students can sit still one minute for each year of age. That may be stretching things for teenagers. *VS America*, a division of a German manufacturer of educational furniture, offered the argument that dissipating the excess energy that contributes to distractibility can be achieved by proper furniture design (VS America, in press). Their version and vision of *ergonomics*, the study of the fit between human anatomy and the designed world, includes chairs that wiggle. According to company representative Amanda Wiegel (personal communication, August 15, 2011) this type of seating design comes in several styles and "Each one functions in a different way to achieve optimized movement and thereby promoting an increase of blood and oxygen to the brain. As a result, attention spans grow longer, and the ability to concentrate improves" (see Figures 4, 5, & 6).

Most chairs are rigid, and do not allow movement in any direction, much less three-dimensional torsion. The chairs that wiggle not only allow the back to push backward, to accommodate a stretching movement, but also allow flexing of the seat and back in all axes. This type of chair is not a prison for sitting. It invites unconscious squirming to be dissipated and thereby becomes a platform for attention and learning.

Figure 4. Chairs that Wiggle – The Hokki

Note. Designed by John Harding of the UK to be used as a temporary active seating solution for people of every age group.

Source: A. Wiegel of VS America. Copyright 2011 by VS America. Used with permission.

Figure 5. Chairs that Wiggle – The PantoSwing

Note. Originally designed by Vernor Panton, the chair's frame is a singular tube that is bent to form a cantilever base that is capable of titling both frontwards and backwards.

Source: A. Wiegel of VS America. Copyright 2011 by VS America. Used with permission.

Figure 6. Chairs that Wiggle – The PantoMove Chair
Note. This design offers three motion options including stationary, rocking front to back, and one that allows rocking in all directions.

Source: Source: A. Wiegel of VS America. Copyright 2011 by VS America. Used with permission.

Collecting the measurements of the human body (anthropometrics) has a long history going back to at least Leonardo da Vinci (Bramly, 1991). This practice continues today through government agencies such as the military and such private groups as the Henry Dreyfus Associates (Tilley, 2002). With all of this information available about the evolving measurements of the "typical" human body it might seem simple to make things the right height for users, but what is the right height? There is no "ideal human," no Greek perfection to model. Therefore, ergonomic furniture, devices that help students be comfortable enough to give their attention to thinking and being creative, need to be adjustable. Height, width, angle of inclination, support geometry for the back and elbows, distance to allow good contact of foot to floor can all be accommodated by good design. The sociology of the classroom is likewise supported by "group ergonomics," understanding the geometry of interaction, of *sociopetal* (relating to others) or *sociofugal* (facing away from others) study. Cornell (2002) summarized the importance of good furniture design toward a creative classroom environment when he stated, "If properly designed and placed, furniture is more than a place to sit; it can be a strategic asset" (pp. 41-42).

Resources. Motivation has a direct correlation with successful student creativity. Students are not only motivated by the teacher but also by what the teacher gives them to use in their problem solving activities. Having available resources in your classroom that students are free to use facilitates their creative output (Amabile, 1996; Csikszentmihalyi, 1996). One way to organize some resources is to have a "tech box," like the designers and engineers who work for IDEO, a global design consultancy. "The Tech Box is a valuable resource that designers and engineers use to gain inspiration, break out of a holding pattern, or merely avoid reinventing the wheel" (IDEO, 1999, para. 3). The tech box is an organized set of drawers containing supplies, materials, trinkets, and toys that may be used in the innovation and design of new products. Having supplies, like those in the tech box, can motivate and give students the opportunity to become more creative.

The types of consumable resources made available to students to encourage creativity through design should be as varied as possible to provide rich opportunities for the use of imagination toward solving problems and making design decisions. Kimbell (1982) summarized the role of resources and, by inference, the need for access to a wide range of materials in a design education foundation course when he stated that such a course "should offer [students] opportunities for direct personal exploration of materials in the solving of simple design problems. Whether these problems are based on tin cans, or strips of softwood, or elastic bands and cotton reels is of little consequence" (p. 147).

Along with readily available supplies a creative classroom environment must also have easy access to an abundance of rich information. Doyle (1991) found that "factors related to information resources ranked highest in importance" (p. 239) in the results of his research on physical facility factors for technological problem solving in secondary technology education programs. Information resources can be made available to students through books and magazines stored in a reading area of the classroom/lab. Computers with Internet access can also provide a vast amount of information at the students' fingertips. Other important information related resources include printers, cameras, scanners, and office supplies.

Sensory variables. Sensory variables play a large role in the students' comfort in a classroom. The most important sensory variable is in regard to ambient temperature. Temperature has an impact on the students' energy and creative output. If a classroom is warm students will most likely be tired and lethargic. According to Gallagher (1993), Lloyd (2001), and Graetz and Goliber (2002), the ideal setting is slightly on the cool side to allow students' creative energies to flow. Many who write about classroom environments that encourage creativity note that the availability of fresh air is highly important (Lloyd, 2001; Christensen Hughes, 2002; Schoolzone, n.d.). Being able to control the temperature and having a flow of fresh air encourages movement and activity.

The acoustical environment can also affect moods and creative performance. Music is a tool that can be used in the classroom to help with students' concentration and overall creative performance (Allen, 2011). "Music has the power to affect people's mood and mood affects performance" (Lloyd, 2001, p. 16). To set the working mood in the classroom, music such as jazz and classical can be played to stimulate concentration, enable creative design, and enhance critical thinking. Jedynak (n.d.) recommended jazz and classical styles of music "because they often do not have lyrics or words, unlike most pop and rock music. Words may actually distract students and limit their responses and interpretive images" (para. 5).

Space configurations. The geometry of the classroom matters, and it matters in different ways depending largely on the age of the students and the activities they are pursuing. Relatively few classroom teaching processes, including the one-teacher active lecturer, actually need or benefit from a fixed geometry of seats and rows. Most classrooms function as arrays of teaching "zones" that are particularly good at supporting one or sometimes two specialized learning activities. This orientation identifies the space as part of the learning environment, rather than the teaching environment. Different kinds of learning need different kinds of space. A creative learning environment can be achieved by having flexible classroom and lab space with furniture, machines, and tools on wheels to be moved depending on the activity or lesson needs.

Teachers sometimes react negatively to spaces that have some odd geometric aspect such as an odd angle; a corner jutting inward; or a wall partly dividing the space into equal or unequal portions. In a number of cases, this negative response reverses when actually laying out the learning spaces. They are usually most successful as sub-spaces with some degree of definition within the larger classroom. Color and light, floor treatment, and arrangement of furniture are usually the devices used to shape sub-spaces. The ideal space would have high ceilings to create a sense of openness.

Another approach is a classroom that literally turns, curves, or is L-shaped. Such geometries actually induce the likelihood of having a variation of activities, of gathering population size and focus. Some schools, using relatively small class sizes of 16 to 18 students, may have a moveable partition that divides that class from an adjacent class of same age students. Usually, in this situation, the two teachers run their classrooms on a coordinated basis and, as circumstances require, open the divider for both groups to work together or to share some results of their work.

There are so many factors involved in successful classroom geometry that it is difficult, if not possible, to isolate one factor and say "it works well if (fill in the blank)." Rather, it is the combination of factors that make a classroom work, from light, to color, to shape, and the rest, all at a threshold whereby they support each other and become home to the creative learning process.

Class size. The final significant environmental variable that affects students' creative energies is class size. Class size may be the most important variable, but in many school districts it is very difficult to control. With the changing economy and the cutting of school budgets controlling class sizes may soon be impossible, unless teachers and school administrators understand and stress the importance of smaller class size. Research has shown that smaller class sizes are more conducive toward student learning. As an example, Finn and Achilles (1990) and Mosteller (1995) found, through a statewide study performed in Tennessee, that class size does indeed influence student learning and academic performance during the early, formative years of elementary school, and that these influences continue at least for several years. The analysis made by Finn and Achilles for the first phase of the research concluded

> The results are definitive: (a) a significant benefit accrues to students in reduced-size classes in both subject areas [reading and mathematics] and (b) there is evidence that minority students in particular benefit from the smaller class environment, especially when curriculum-based tests are used as the learning criteria. [Abstract]

Mosteller's (1995) analysis of the longitudinal aspect of the research concluded "the children who were originally enrolled in smaller classes continued to perform better than their grade-mates (whose school experience had begun in larger classes) when they were returned to regular-sized classes in later grades" (p. 113).

Other research findings indicated that the ideal class size is 25 students or less (Ohio Education Association, n.d.). Many teachers would prefer to lower that number to fewer than 20 students in a classroom to aid with classroom management. Classroom management is improved through fewer learning and behavior problems, which can develop when students are not able to adequately interact with the teacher. Lowering the class size results in improvements in a variety of important learning factors, including creative behavior, problem-solving abilities, retention of material learned, and an increase in opportunities for participation and expression (Ohio Education Association, n.d.; Resnick, 2003).

CONCLUSION

Classes in technology education can have a tremendous impact on students and the futures they choose for themselves. Knowing how to use one's creativity is an asset, which has increasing value in an ever-changing global environment. As a result, teachers have an obligation to help shape their students into creative thinkers who can then actively design their own lives. The implementation of problem solving and team-building activities as well as changing the classroom from teacher-centered to student-centered are fundamental steps toward achieving this goal. As the first-hand experiences recalled, and the research investigated in this chapter indicated, the physical classroom environment has a direct correlation to the creative output of students. If you truly embrace creativity and design as basic tools for teaching and learning about technology, updating your classroom/laboratory should be on the top of your agenda.

REFLECTIVE QUESTIONS

1. Why is the environment in which we teach and learn so important toward learning and creativity?
2. There are many environmental variables affecting the classroom. Which do you believe to be most important? Are there other variables that could affect students' creativity?
3. Does your classroom environment enhance the creative potential of your students? If not, what changes could you make to develop a creative classroom environment?
4. What would your classroom and laboratories look like if you were given the opportunity to develop a technology education department that would use creativity and design as the foundation toward teaching and learning about technology?

REFERENCES

Albers, J. (1971). *Interaction of color: Text of the original edition with selected plates* (Rev. ed.). New Haven, CT: Yale University Press.

Allen, R. H. (2011). A cornucopia of useful points regarding music. Retrieved from the Songs for Teaching: Using Music to Promote Learning website: http://www.songsforteaching.com/richallen/cornucopia.htm

Amabile, T. M. (1996). *Creativity in context.* Boulder, CO: Westview.

Andy Warhol. (2002). Retrieved from http://www.famouspainter.com/andy.htm

Birren, F. (Ed.). (2003). *The elements of color: A treatise on the color system of Johannes Itten based on his book The Art of Color* (E. Van Hagen, Trans.). New York: John Wiley. (Original work published in German in 1961)

Boynton, M. & Boynton, C. (2005). *The educator's guide to preventing and solving discipline problems*. Alexandria, VA: Association for Supervision and Curriculum Development.

Bramly, S. (1991). *Leonardo: Discovering the life of Leonardo da Vinci* (S. Reynolds, Trans.). New York: Edward Burlingame.

Chism, N. (2002, Winter). A tale of two classrooms. In N. V. N. Chism and D. Bickford (Eds.), *The importance of physical space in creating supportive learning environments.* New Directions for Teaching and Learning, 92 (pp. 5-12). San Francisco: Jossey-Bass.

Christensen Hughes, J. (2002, Winter). Developing a classroom vision and implementation plan. In N. V. N. Chism and D. Bickford (Eds.), *The importance of physical space in creating supportive learning environments*. New Directions for Teaching and Learning, 92. (pp. 63-72). San Francisco: Jossey-Bass.

Cornell, P. (2002, Winter). The impact of changes in teaching and learning on furniture and the learning environment. In N. V. N. Chism and D. Bickford (Eds.), *The importance of physical space in creating supportive learning environments.* New Directions for Teaching and Learning, 92 (pp. 33-42). San Francisco: Jossey-Bass.

Csikszentmihalyi, C. (1996). *Creativity: Flow and the psychology of discovery and invention*. New York: Harper Collins.

Daugherty, M., Klenke, A., & Neden, M. (2008, October). Creating standards-based technology education facilities. *The Technology Teacher*, *68*(2), 19-26.

Dondis, D. A. (1973*). A primer of visual literacy*. Cambridge, MA: MIT Press.

Doyle, M. (1991). *Physical facility factors for technological problem-solving activities in secondary technology education programs*. Unpublished doctoral dissertation, West Virginia University, Morgantown.

Finn, J. D. & Achilles, C. M. (1990/Fall). Answers and questions about class size: A statewide experiment. *American Educational Research Journal*, *27*(3), 557-577. Retrieved from http://www.jstor.org/stable/1162936

Frida Kahlo. (2002). Retrieved from http://www.famouspainter.com/frida_kahlo.htm

Gallagher, W. (1993). *The power of place: How our surroundings shape our thoughts, emotions, and actions*. New York: Poseidon.

Georgia O'Keeffe. (2002). Retrieved from http://www.famouspainter.com/georgia.htm

Graetz, K., & Goliber, M. (2002, Winter). Designing collaborative learning places: Psychological foundations and new frontiers. In N. V. N. Chism and D. Bickford (Eds.), *The importance of physical space in creating supportive learning environments.* New Directions for Teaching and Learning, 92 (pp. 13-20). San Francisco: Jossey-Bass.

Herschbach, D. R. (2009). *Technology Education: Foundations and perspectives*. Homewood, IL: American Technical Publishers.

Hyerle, D. (2000). Thinking maps: Visual tools for activating habits of mind. In A. L. Costa, B. Kallick, and D. Perkins (Eds.), *Activating and engaging habits of mind* (pp. 46-58). Alexandria, VA: Association for Supervision and Curriculum Development.

IDEO. (1999). *Tech box for IDEO*. Retrieved from http://www.ideo.com/work/item/tech-box/

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author.

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology*. Reston, VA: Author.

Jedynak, M. (n.d.). Classroom techniques: Using music in the classroom. *English Teaching Forum, 38*(4). Retrieved from U. S. Department of State, Bureau of Educational and Cultural Affairs website: http://eca.state.gov/forum/vols/vol38/no4/p30.htm

Kimbell, R. (1982). *Design education: The foundation years*. London: Routledge & Kegan Paul.

Lloyd, P. (2001). *Creative space.* Retrieved from http://www.gocreate.com/articles/cspace.htm

Madsen, M. (n.d.). Light-zone(s): as concept and tool (The Royal Danish Academy of Fine Arts, School of Architecture). Retrieved from The Daylight Site website: http://www.thedaylightsite.com/research.asp?tp=6

Moon, D. E. (1975). Introduction. In D. E. Moon (Ed.), *A guide to the planning of industrial arts facilities* (pp. 15-20). Bloomington, IL: McKnight.

Mosteller, F. (1995, Summer/Fall). The Tennessee study of class size in the early school grades. *The Future of Children: Critical Issues for Children and Youths*, *5*(2), 113-127. Retrieved from http://www.jstor.org/stable/3824562

Nelson, L. P. (1981). Background: The European influence. In R. Barella and T. Wright (Eds.), *An interpretive history of industrial arts* (pp. 19-47). Bloomington, IL: McKnight.

Ohio Education Association. (n.d.). *The question of class size* [Abstract]. (ERIC Document Reproduction Service No. ED133325)

Osterhaus, W. (n.d.). *Design guidelines for glare-free daylit work environments* (Aarhus School of Engineering). Retrieved from The Daylight Site website: http://www.thedaylightsite.com/research.asp?tp=6

Peterson, R. E., & Harrison, H. L. (2005, March). The created environment: An assessment tools for technology education teachers. *The Technology Teacher, 64*(6), 7-10.

Pytel, B. (2006, August). *Color and learning: How does color affect our thinking and feeling?* Retrieved from http://www.suite101.com/content/color-and-learning-a3246

Resnick, L. (Ed.). (2003, Fall). Class size: Counting students can count. *Research Points, 1*(2), 1-4. Retrieved from http://www.aera.net/?id=314

Sanders, M. (2001, Spring). New paradigm or old wine? The status of technology education practice in the United States. *Journal of Technology Education, 12*(2), 35-55.

Schoolzone. (n.d.). *Redesigning the classroom environment.* Retrieved from http://www.schoolzone.co.uk/resources/articles/GoodPractice/classroom/Redesigning.asp

Smith, D. F. (1981). Industrial arts founded. In R. Barella and T. Wright (Eds.), *An interpretive history of industrial arts* (pp. 165-204). Bloomington, IL: McKnight.

Tilley, A. R. (2002). *The measure of man and woman: Human factors in design*. New York: John Wiley & Sons.

VS America. (in press). *VS product information: The Hokki*. [Booklet]. Charlotte, NC: Author.

Walker, R. (2007). Peak physical conditions: Environmental ingredients for learning. *Physical Factors, 5*(2), 24-27.

Warner, S. A., & Myers, K. L. (2010, December/January). The creative classroom: The role of space and place toward facilitating creativity. *The Technology Teacher*, *69*(4), 28-34.

Warner, W. E. [with Gary, J. E., Gerbracht, C. J., Gilbert, H. G., Lisack, J. P., Kleintjes, P. L., and Phillips, K.] (1953). *The industrial arts curriculum: Development of a program to reflect American technology.* [Proposal]. Columbus, Ohio: Epsilon Pi Tau. (Original work presented at the American Industrial Arts Association Conference in 1947)

Wright, T. (1981). Manual training: Constructive activities enter the public schools. In R. Barella and T. Wright (Eds.), *An interpretive history of industrial arts* (pp. 87-129). Bloomington, IL: McKnight.

Cultural Environments for Creativity and Design-A Case Study

Chapter 9

Jennifer Baker
Charter High School for Architecture + Design (CHAD)

According to Lubart (1999), "Creativity does not occur in a vacuum" (p. 339). There are an untold number of variables within a given environment that influence the creative potential and productivity of people. Lubart identified a partial list of those environmental variables, which included "the physical setting, the family, the school or workplace, the field of endeavor, and the culture" (p. 339). Broadly defined, a culture is any group of people that share common values, beliefs, and knowledge that is then transmitted among the members of the group and from generation to generation through language, stories and histories, artifacts of the arts and sciences, rules of behavior, education, and spirituality (Culture, 2006; Peace Corps, 1997; Roshan Cultural Heritage Institute, 2001).

The social/cultural environment, both large and small, can encourage as well as discourage creativity. Geographers and sociologist sometimes refer to the large social/cultural contexts as macro-cultures and the smaller contexts as micro-cultures. Neuliep (2008) defined macro-culture as the dominant culture within a group of people, which extends to a large geographic scale such as the city, state, region, or nation. Micro-cultures exist within the larger macro-culture. They typically encompass small groups, such as the family, immediate friends, co-workers, school groups, or tribes/sects, who live and work within defined geographic areas. Neuliep defined a micro-culture as

> An identifiable group of people who share a set of values, beliefs, and behaviors and who possess a common history and a verbal and nonverbal symbol system that is similar to but systematically varies from the larger, often dominant cultural milieu. (p. 112)

It is within the context of a micro-culture that this chapter will examine the characteristics of the Charter High School for Architecture + Design (CHAD) in Philadelphia, Pennsylvania. This examination explores how that school's culture both shapes and is shaped by design, which plays a central role in the organization and implementation of the school's curriculum. The CHAD example demonstrates that design education pedagogy, applied in a cultural environment for creativity and design, can be a blueprint for educational reform. According to KEA European Affairs (2009), design education can be the critical creative currency that transforms the circumstances of students' lives thereby creating cumulative socio-economic change. A design-based education can serve as the key of admittance for high school students into universities and colleges from which they graduate and become members of the larger creative economy.

Florida (2002) developed a theory of human behavior that he called "the creative capital theory" (p. 223). This theory is based upon the premise that creative people will tend to group together in geographic regions and that their creative energies will be the power behind the economic growth and vitality of those regions. Florida asserted that creative people "prefer places that are diverse, tolerant and open to new ideas" (p. 223). Florida's study of creative people also indicated that they address the questions of where to live and work differently than previous generations. At the top of the list of questions were matters related to the depth of the local job market. Job related questions were considered to be so important because statistically, fewer people work for the same company all of their lives as would have been the case for workers in the past. Other types of questions asked by creative people in considering where to live deal with overall lifestyle issues such as the availability of music, art, technology, sports, and other cultural opportunities. The availability of venues such as coffee shops, cafes, bookstores, and pubs, the diversity of the local community, and the potential of that community to serve as a source of personal identity/affiliation provide another set of filters by which the creative class determines what Florida called "quality of place" (p. 231). As one can imagine, a whole school of students engaged in answering these essential questions results in the formation of a micro-culture, a small collective of creative people imagining new worlds for themselves and others. Motivated by meaning and certain that with a developed plan, mastered skills, technological savvy, and a loaded portfolio they can build from their imagination a new reality in the form of original solutions, programs, and products. CHAD, as a result, represents a cultural environment for creativity and design.

This chapter presents components of CHAD's design curriculum and pedagogy as teaching tools for the reader to use to transform the culture of their school. The goal of this chapter is to provide examples of processes, procedures, and methodologies for teachers to adopt and integrate into programs that could prepare students for today's creative economy.

CHAD'S HISTORY AND DEMOGRAPHY

This public charter high school was founded by the American Institute of Architects (AIA), Philadelphia Chapter, as the Legacy Project for the AIA National Convention held in Philadelphia in May, 2000. As the first charter school of its kind in the country, CHAD opened its doors to approximately 400 students in grades 9 through 11 in September, 1999, and graduated its first class of 49 seniors in June, 2001. In 2011, CHAD enrolled approximately 600 students (Charter High School for Architecture + Design, n.d., a).

Prospective students choose to come to CHAD rather than their neighborhood schools for a variety of reasons that are separate from seeking membership in a design-based learning community:

- CHAD'S neighborhood is safer than many neighborhoods in Philadelphia;
- CHAD is in a convenient location close to public transportation; and
- CHAD has free tuition.

The majority of incoming ninth grade students usually have not had a broad perspective on design education but have enjoyed drawing and art classes. Some of these ninth graders have had a high quality, standards-based visual art education at the elementary and middle school levels. Others have not had an arts education but instead instinctively, intuitively, independently enjoy drawing or building things with their hands. Students have come to CHAD from over 50 different zip codes in the Philadelphia area. CHAD has had students from 72 different elementary and middle schools, including public, parochial, independent, and charter schools. A majority of the recent applicants have come from charter schools.

In addition to the typical challenges of adolescence, many CHAD students also endure the hardships that accompany poverty in an urban setting: poor nutrition, the loss of a parent or a family member to violence or health problems, homelessness, and parents working two and three jobs with no spare time. Many CHAD students receive social and counseling services and emotional support. Typically, 55% of the incoming ninth grade is three grade levels behind in reading and math.

CHAD faces unusual barriers in achieving academic equity and continuity within the student body. Because students come to CHAD in ninth grade from so many entry points (i.e., geographically, economically, and academically), it is particularly difficult to track patterns and address areas of academic need. All CHAD students take benchmark tests to inform the faculty and comply with School Reform Commission requirements. Students receive regular testing, coaching, and support with the goal of scoring well on the Pennsylvania System of School Assessment in the 11th grade and on the SAT in 12th grade.

CHAD does not provide a traditional high school experience; it offers no extra curricular electives and no general physical education program. What CHAD offers is a highly specialized experience with an intense daily schedule and a clear focus on architecture and design and college acceptance. The end goal for the whole school community is 100% high school graduation and 100% college placement for CHAD students. As CHAD Board member Tony Bracali noted,

> We don't want all our students to become architects. More and more studies are showing the measurable, positive impact of design on people's social, physical and mental health. We'd like them to leave CHAD with an appreciation for how design can improve their lives and the lives of others. (Charter High School for Architecture + Design, n.d., c)

CHAD is a Title I school that focuses on improving the academic achievement of disadvantaged learners. Title I of the Elementary and Secondary Education Act "is to ensure that all children have a fair, equal, and significant opportunity to obtain a high-quality education and reach, at a minimum, proficiency on challenging State academic achievement standards and state academic assessments" (U.S. Department of Education, 2011) [1].

There is a two-part application process enabling students to apply to CHAD. Prospective students are required to submit drawings, write an essay, and participate in a school visit and an interview. The admissions process is structured to provide prospective students with a realistic sense of the school and its culture to ensure that the student applicant understands the explicit, intentional design of the school as distinct from any other. In some cases, the incoming students have not chosen CHAD, rather their parents have. Ideally, a prospective CHAD student self-selects whether or not CHAD is the right school to attend.

CHAD's Community and Structure

CHAD is located within America's most historic square mile at Seventh and Sansom Streets in Philadelphia. Teachers are able to walk with their students to the Liberty Bell, Independence Hall, Independence National Park, Washington Square, The Athenaeum (A private architectural library), The Betsy Ross House, The Constitution Center, The National Liberty Museum, the waterfront of the Delaware River, and many other historically significant locations. Strong relationships with these cultural institutions provide real world partners for the school as well as critical internships, mentor relationships, interschool collaborations, and competitions.

The schedule is flexible and changes from year to year based on the needs of the school and those of our students. The school day begins at 8:00 a.m. and ends at 3:30 p.m. Because there is only one lunchroom, which can only serve lunch for a quarter of the student body at a time, the lunch schedule is the primary factor that affects how the master schedule is planned. In 2010-2011, students attended 95-minute blocks of general education classes plus a 95-minute intra-curricular block of design. While the schedule for faculty and students has changed throughout the years, CHAD has always honored the commitment to a major allocation of time for design studio.

Design studio has been included as a daily class, and has always been allocated between 70 minutes and 100 minutes per day. Design class period occupies the time that most other schools allow for electives such as music, drama, and art. The block schedule exists to provide the opportunity for a true studio experience in a design class and to enable students with extra time in general education classes to maximize their learning. Teachers of general education subjects have the class time to employ project-based learning methods. Clubs and tutoring are available after school. The block schedule is critical to the success of the CHAD design curriculum. The extended class time allows for in-depth inquiry, exploration, production, and project-based learning. Having this block of time for design studio each day over the course of a four-year program of study is an invaluable part of the success of the CHAD program. A sample of a typical student schedule is shown in Figure 1 (next page).

Figure 1. A Typical Student Schedule for the 2010-11 Academic Year

2010-2011 WEEKLY SCHEDULE 10th Grade												
Section:	*1*		*2*		*3*		*4*		*5*		*6*	
Day:	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Block 1/HR 8:00-9:45	BIOL	AMER HIST 1	ALGEBRA 1		DESIGN 3		AMER HIST 1	BIOL	ENGLISH 2B		DESIGN 4	
Block 2 9:50-11:25	ALGEBRA 1		BIOL	AMER HIST 1	ENGLISH 2A		ENGLISH 2B		GEOMETRY		AMER HIST 1	BIOL
Block 3 11:30-1:05	ENGLISH 2A		DESIGN 3		GEOMETRY		GEOMETRY		DESIGN 4		ENGLISH 2B	
1:10-1:45	Lunch											
Block 4 1:50-3:25	DESIGN 3		ENGLISH 2A		BIOL (Cooke)	AMER HIST 1 (Rooney)	DESIGN 4		AMER HIST 1	BIOL	GEOMETRY	
3:25	Dismissal											

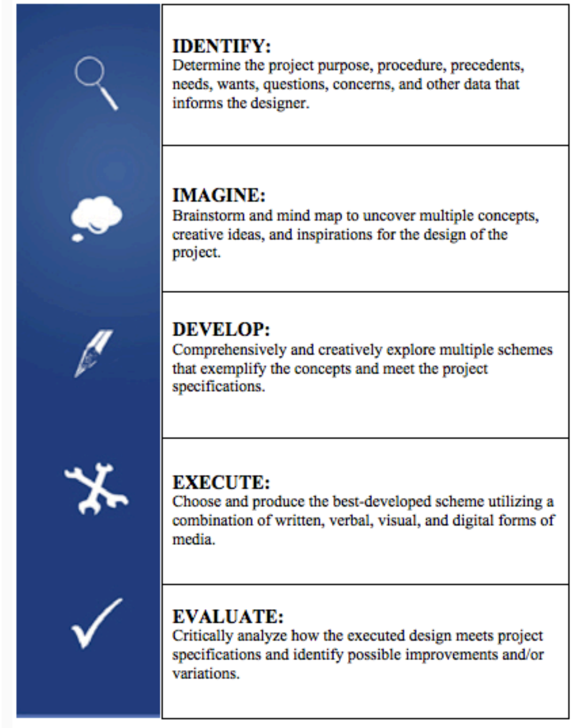
CHAD'S CURRICULUM AND FACULTY

Like any typical public high school, CHAD's general curriculum addresses core subjects such as mathematics, language arts, and science. What differentiates CHAD from most high schools in America is the use of design thinking as its organizing principles in all of its subject areas (see Figure 2, next page). CHAD's website describes its academic curriculum as follows:

> CHAD teachers strive to create dynamic, student-centered classrooms in which democratic principles thrive. Our fluid curriculum is authentic: it reflects the real world, responds to our students' interests and lives, and prepares them to be active, life-long learners. Our teaching is shaped by varied and valid assessments. We ask students to transform problems into possibilities. Assessments are used to inform student self-reflection and teacher instruction. Through differentiated instruction, each child is both nurtured and challenged to continually reach for and expand his or her own potential. We enrich students' intellectual growth through process and skill-oriented learning. Students are

> asked to be accountable for the quality and integrity of their academic endeavors. We demand active participation, clear expression, sophisticated thinking, and high-level work from the members of our community. (Charter High School for Architecture + Design, n.d., b)

Figure 2. The Design-Based Paradigm of CHAD's Curriculum



The CHAD design curriculum requires students to take two semesters of design almost every year for four years. A different design teacher teaches each semester. Teachers are assigned to specific grade levels. The CHAD design faculty members are practicing architects, commercial illustrators, professional designers (industrial, fashion, and graphic design) and fine artists. Fifty percent of the design faculty is certified in art education and 100% are credentialed professionals in recognized fields of design and architecture. Currently, there is one design faculty member who is also a CHAD alumnus.

The particular experience and expertise of each design teacher drives the content of lesson plans. Design teachers teach one-half of a grade level for a 16-week semester and then rotate students with their grade level counterpart. The semesters are designed to encompass design, architecture, fine arts, problem solving, and critical thinking skills. Generally, across all four years one semester is more focused on architecture + design and the other is oriented toward fine arts. Planning and collaborative components of the prescriptive curriculum intentionally ensure overlap, crossover, and integration of fine arts, design, and architecture.

There is a scaffolded architecture + design skill set that drives the entire curriculum. Originally, this skill set focused on proficiencies of drafting, drawing, sketching, 2-D and 3-D-design, and design process. This skill set was created by department consensus during the early days of CHAD. The gestalt of this skill set establishes a firm foundation of design skills. These fundamental design skills for students remain at the core of the essential skill set for CHAD students, despite changes in the faculty, units of study, and changing national and state standards.

A review of the skill set expectations for the 2010-2011 academic year, as collectively determined by the design faculty at CHAD, indicates that there are at least 10 common skills that students are expected to develop (Design Style Book Master, n.d.). Those skills are identified in Figure 3.

Figure 3. The Most Common Skills that CHAD Students are Expected to Develop as Determined by Department Consensus

Design Based Skill Sets

Critical thinking

Building/Creating/Making

Presentation

Evaluation/Critique

Problem Solving

Brainstorming

Analysis

Research

The design department is committed to teaching a deliberately planned curriculum framework, which includes foundation skills, interdisciplinary education, new methods, materials and technique, the incorporation of state standards, and 21st century skills. All of these curricular elements are embedded in the department's constant use of the design process and a hands-on approach of the design practice. Part of the design class is academic studies, which revolve around production. The planning of projects requires adherence to curriculum and sequence as well as alignment of teaching and learning with national standards.

THE DESIGN PROCESS IN THE MICRO-CULTURE OF CHAD

Regardless of the specific content area, design and design thinking are integral to the teaching and learning experiences at CHAD. This approach to teaching and learning is so fundamental to the philosophical organization of the school that it is promoted in various public forums such as the CHAD website, which states

> CHAD emphasizes the use of the design process across the curriculum as a vehicle for creative and analytical thinking. CHAD's program provides students with the opportunity to understand the design process through creative and disciplined exploration. Important to this process are [production based] studio activities that involve [and require] structured investigation, self-reflection, critique, aesthetics, historical context, and multiculturalism. CHAD builds the confidence needed to explore problems, take risks, and turn challenges into numerous possibilities. Students learn to design in response to both the user and the environment. (Charter High School for Architecture + Design, n.d., b)

STUDIO TOOLS, EQUIPMENT, AND MATERIALS

It is critical for CHAD students to be introduced to a variety of tools and materials. The introduction to professional tools and materials occurs during the first year. As students proceed through the curriculum their exposure to tools and materials increases. As Cross (2000) observed, "The world is . . . full of tools, utensils, machines, buildings, furniture, clothes, and many other things that human beings apparently need or want in order to make their lives better" (p. 3). Engaging students with the tools, equipment, and materials, such as those identified by Cross, connects them at a personal level with the many resources of design. Petroski (1985) observed, in the context of engineering, that this level of engagement enables students to consider more design options to a greater depth, with a functional appreciation of the properties and operational characteristics of the tools, equipment, and materials than conceptual understanding alone would allow.

The 2010-11 budget for the design department allocated $25,000 to be distributed to the eight design studios ($3,125.00 per class) for classroom supplies. The final “price tag” breakdown per student was $45.21 per student for the academic year. Each design teacher was responsible for maintaining an annual budget and placing orders for tools, equipment, and materials.

The basic studio needs that were covered by this budget are

- *Equipment:* Replace or add classroom equipment, such as printing presses, drying racks, woodworking tools, and storage containers.
- *Classroom Tools:* Project tools (e.g., drafting boards, cutting boards, metal rulers, scissors, stencils) and hand tools, teaching books, and posters in the classroom.
- *Consumable Supplies:* Materials used to execute projects, including paint, pencils, paper, chipboard, butter board, and glue.

In addition to the expenditure for the classroom supplies, other supplies have cost approximately $6,200 annually. These supplies included student sketchbooks at $3,300, student portfolios at $2,500, and exhibition supplies at $400.

STUDIO CULTURE AND SPACE

CHAD presents a specific studio culture. Creative professionals layer their own expertise into lesson planning and delivery. Teacher accountability for the supervision of tools and materials is built-in, as the budget is finite. Students are exposed to new materials, tools, skill sets, and concepts in the design studio. Transformation occurs as students acquire studio culture skills and learn to independently navigate through the space of the design studio.

Incoming freshmen, new to the CHAD culture, have most often come from schools where “art class” was perceived as a break for students. In some elementary schools, art class is perceived as a recess that is filled with unstructured time and limited materials. This experience results in students not knowing how to behave in a creative workspace nor how to use and care for tools and materials.

No matter where the students come from, there is a clear adjustment period at CHAD that requires students to recognize and value new resources critical to the creative culture: time, materials, people, ideas, capital, finance, and energy. Students are explicitly taught to care for and maintain tools, materials, and personal work. In many classes, a grade is earned for the responsible care of tools and materials. As students move through grade levels, they use more advanced tools and materials and earn more freedom and independence to move freely through the design studio.

By their senior year students are expected to complete a "senior project." This project requires that students are able to navigate independently in the design studio. They can get and put away their materials. They manage their time, set their own goals and are expected to present their finished work at the culminating CHAD event, the Senior Show. During the senior project class period, the teacher's role is transformed from deliverer of direct instruction into that of a resource, collaborator, and coach. Peer collaboration and review, which has been taught explicitly throughout the CHAD experience, becomes a natural part of student communication as students work alongside one another. This atmosphere of studio culture, which exists at the college level, is one of the reasons CHAD students fare exceedingly well in their design courses at the undergraduate level.

The eight studio spaces at CHAD inform the studio culture. Design studios share the features of large worktables that seat three to four students, storage cabinetry, a small teacher-owned resource library, evidence of student work, teacher-made signage, and didactic tools and resources. These didactic resources include cultural artifacts, professional references, exemplary projects, and a projector connected to a teacher computer. Computer laboratories representing both Windows-based and Apple platforms are available as ancillary facilities.

Each studio space—managed by a design teacher—accommodates an average class size of 26 students. The studios vary in physical size and layout from 26' x 40' to 32' x 60'.

Teachers and students must adapt to the variables of each studio space. Like many Charter schools, CHAD operates out of a building that was not originally designed or built to be a school (see Figure 4, next page). The result is a non-traditional retrofit school space. Therefore, each studio is different. It is a design challenge in and of itself to make each space work. Some studios have natural light and a sink and others do not. Many of the rooms are unusually shaped spaces.

In almost all of the studios the furniture was either made out of available materials such as doors and inexpensive lumber or donated supplies. Teachers are free to set up studios as they like, and often reconfigure classrooms during the semester by changing table groupings to suit their lesson plans and to maximize student engagement (see Figure 5, next page).

Figure 4. The Charter High School for Architecture + Design

Note. Located in downtown Philadelphia, CHAD is in a multi-story building that was not originally intended to be used as a school. Photograph owned by author, used with permission.

PEDAGOGY OF PRODUCTION

Design studio at CHAD offers students opportunities to transfer academic and intellectual theory into projects within a production-oriented setting. The CHAD Design Process is introduced in ninth grade and is used throughout all four years at CHAD. It is a methodology, which enables design teachers to break down a project into identifiable steps. This process, used repeatedly, becomes production pedagogy in and of itself. Students learn to approach problems, imagine multiple solutions, develop the most effective solution, execute said solution, and then evaluate both the process and the product. Within the design process students learn a multitude of design organizational skills such as mind mapping, listing, sketching, and drafting. The design process is not complete without the act of production. Production itself becomes content and processes that students learn as they create solutions to solve unique problems. The philosophy of "learning by doing" is the foundation of a culture that allows students to find answers to problems, which are not listed as multiple-choice answers on a test. Students are empowered to take chances, extend and apply individual creativity, and risk failure to solve a problem and gain success. Finally, when success is achieved and a finished product is ready for presentation the designer experiences the satisfaction of being able to explain and defend the creative and organizational process as well as having pride in an authentic product and solution.

Figure 5. A Senior Design Studio at CHAD

Note. Design studios provide students with lots of space, plenty of light, table surfaces for drawing and production purposes, display areas and storage shelves for resources, and flexibility so that the room can be reconfigured, as circumstances require. Photograph by author, used with permission.

Student portfolio overview. The CHAD student portfolio is both a program and a process with a targeted practical end goal: College acceptance and scholarships. The student portfolio is physical, aesthetic evidence of the CHAD design curriculum and the individual's application and synthesis of content taught. Each student's portfolio reflects the time spent in design studio and an exposure to specific pedagogy that delivers a design education. The student portfolio is also an artifact that demonstrates the distinctively different high school trajectory that CHAD offers.

Each design teacher aims to lead students through four to seven projects every semester. These projects are defined and discussed as "portfolio pieces." The projects include two and three-dimensional work. 2-D work is contained in portfolio boxes. Both the 2-D and 3-D work is photographed and the images are stored and organized on the school server. During the first semester of the senior year students use the images collected over their entire high school career to create a personal exhibit displayed for the entire community. As such they must meet the standards of the design department portfolio policy. That policy is built upon a mission statement that reads

> The CHAD Portfolio Program is a program that teaches students the importance of creating, storing, and documenting work in order to use it as a requirement for the college application process. All architecture, design and art schools ask for approximately 12-20 portfolio pieces in order to fulfill the portfolio requirement. A significant impact that the portfolio program has for CHAD seniors is the ability to acquire merit scholarship funding for college when the portfolios are well maintained and developed. It is imperative that all design instructors adhere to the structure of the program in order to ensure what is best for the student. The preservation of each student's work aids in his/her ongoing professional presentation skills as well as serving to acquire college acceptance and funding. (Durkee, 2011, p. 1)

The design department's portfolio policy documents the various responsibilities each design instructor is responsible for addressing to assure that all students create professional quality portfolios. The identified responsibilities deal with such things as the number of portfolio pieces in a specific course or at a grade level, the quality standards for each of those pieces of work, opportunities and expectations for public display of student work, and procedures required for each teacher to document actions taken by students to add to their portfolio. Work to be included in a student's portfolio can come from a variety of design-focused subject areas such as architecture, graphic design, industrial/product design, fine arts (e.g., drawing and painting), 3-D work, fashion design, and printmaking. The portfolio policy document also provides extensive lists of examples of artifacts for each of these design-focused subject areas. Arguably, the CHAD portfolio is the collateral that sets CHAD students apart from other high school students nationwide.

Portfolios for college admissions. Students travel to and from school using public transportation—often traveling as much as one hour each way—making it impractical for students to bring their design work to and from school. In addition to challenges with public transportation, many students travel between households during the week, going back and forth between the homes of family or guardians. Many students also have after-school jobs. Therefore, it is necessary for students to have a personal storage system at school to organize and keep their finished work. Students who attend CHAD receive one 28" x 36" x 2" corrugated cardboard portfolio case in addition to their yearly sketchbook. Each case is intended to last for all four years. The cost is built into the annual student fee. The portfolios are stored as a grade level grouping and are moved as such to an area that is accessible by the teacher and also by students under adult supervision. The portfolio case is not intended to store all student process work such as sketches, warm ups, or rough drafts; rather, it is meant to hold and protect finished mounted work, which will be photographed and used later for the purpose of pre-college and college applications. Students are discouraged from taking home, giving away, or selling any of their original work. They are explicitly told that doing so may reduce their opportunities for scholarship money. Owning a portfolio case, as well as the act of cultivating artifacts for it and caring for the work within it, require students to understand and protect the value of their creations. Early on students at CHAD begin to see the value the faculty and school put on portfolio work. CHAD students learn the monetary and philosophical value of the design work they complete during their high school years. This knowledge is significant as it is a catalyst toward the students' economic independence and viability, separate from their family's socioeconomic status.

Digital portfolios. The digital portfolio is a process and a product. It represents the completion and presentation of the physical portfolio that contains the body of work students create during their time at

CHAD. Each semester the grade level faculty members take time outside of class to label the work of each student. When possible, a photographer is hired to photograph all portfolio work. CHAD has experimented with a variety of processes of photographing the work for the purpose of creating digital portfolios.

Portfolios for assessment. Another goal of developing portfolio pieces is to create a platform for assessment. Students and faculty use rubrics and written or oral critiques to evaluate the criteria for a portfolio piece. Common standards for assessment are shared within the design department. It is not uncommon to overhear students and faculty distinguishing "class work" from "portfolio work." The idea of a "portfolio piece" as a finished piece of work ready to present and be judged has become part of the culture at CHAD. By 10th grade it has become ingrained in the students' minds that a portfolio piece is one that is their best, one that is finished, a piece for which they are proud. The piece reveals mastery of skills and concepts and is ready to display for First Friday or present to a college or pre-college admissions counselor. By senior year CHAD students have personally synthesized state and national standards as well as a set of distinctly different standards specific to the portfolio. The portfolio standards are centered on college admissions expectations, which according to the Design Portfolio Program (Durkee, 2011) includes (a) observational drawing, (b) work demonstrating a mastery of color and composition, and (c) "personal work." In other words, it is work that the student does independently outside of classroom instruction to demonstrate their creativity and future professional interests.

The *oeuvre* of each senior student's work is showcased in a digital portfolio. CHAD students exhibit a mastery of observational drawing and painting skills, an understanding of the elements of art, and the principles of design; and most importantly, a unique point of view with a commitment to creative and critical thinking.

The design portfolio policies and practices ensure that both teachers and students place a heavy value on the systematic cultivation and presentation of student portfolios. These portfolios enable CHAD graduates to be accepted into colleges and universities all over the country, including the top architecture and design schools.

Since the portfolio system was implemented in 2007, each graduating class has cumulatively received an average of 2.5 million dollars in design portfolio-based merit scholarships. This is a significant increase from an average of $500,000 in portfolio-based merit scholarships for each graduating class before 2007.

It is indeed an investment of time, money, and curriculum design to place such emphasis on the student portfolio. The investment pays off when students can show the collateral, the design portfolio, which is their ticket to enter the creative economy. High college acceptance rates look good on paper for any school, but it is the amount of money students receive in merit scholarships that make a lifelong difference for the students who transition to achieve new economic, intellectual, and social status. The portfolio is a currency students can use to achieve this status and capital.

Portfolios for presentation. CHAD students kick off senior-year design studio by working with their teachers to digitize and present their student portfolios. This is an opportunity for students to accrue and synthesize graphic design skills. The 2-D and 3-D work that has been photographed is stored on a server, which students access through the computer lab. Senior design teachers lead students through the process of laying out their work and presenting it in graphically designed layouts. As technology resources evolve so do the platforms for the digital portfolio. Presently, students burn CD ROMS, which are submitted to colleges and universities as part of the application process.

PEDAGOGY OF SPACE

CHAD design faculty use space to enhance or support teaching. Because of our location students can perform primary research tasks for design projects as well as draw and sketch al fresco (i.e., in the open air of the surrounding neighborhood; see Figure 6, next page). Because each teacher has autonomy over how to set up studio space, opportunities exist to supplement the content of units by customizing the classroom. Every bit of physical space within the school informs the inhabitants of the micro-culture of the CHAD community. Classrooms are creative and imaginative, hallways and common spaces are filled with student designs, pedagogy is delivered through signage, teacher-made products, examples of exemplary student work, and visionary works that are provided to CHAD by professional designers and architects. This use of space is intentional because all of the displays help informally teach and communicate values, information, and relative core content.

Figure 6. CHAD Students Engaging with Their Local Surroundings

Note. CHAD students use the nearby park outside of Independence Hall as one of the many historical venues where they can sketch in a visually rich environment. Photograph by author, used with permission.

Gallery exhibition space. Exhibition of both professional and student work is a hallmark of CHAD's creative culture. The halls and walls of CHAD common space are intentionally and explicitly full of design work (see Figure 7, next page). Donated works from national and local architectural and design firms are on display throughout the school. Works from architects include presentation boards, concept boards, site photographs, and three-dimensional architectural models. Works from designers include industrial design prototypes and products, graphic design images, and textiles.

Exemplary student work is displayed throughout the school, including the administrative executive suites. Fiber wallboard (*Homasote* is one brand name for the product) enables the easy hanging of student work and covers a large percentage of CHAD's walls and ceilings (see Figure 8, next page). Lockers also serve as display space. The metal door front of many lockers is replaced with glass so that a display space can be created.

Figure 7. Using Cafeteria Walls to Display Student Work

Note. Photograph by author, used with permission.

Figure 8. Using Every Surface for Displaying Student Work

Note. Even ceilings are considered appropriate territory for displaying student work. Photograph by author, used with permission.

Exhibition events. There are three major exhibitions of student work each year. CHAD participates in one school-wide “First Friday” show per semester and the culminating “Senior Show.” The exhibition space is transformed at CHAD for each show (see Figure 9). Invitations are sent to family members of students and faculty, administration and staff, board members, and other CHAD community members. Six professionals, usually architects and designers and alumni, judge each First Friday show. The Senior Show is not judged as it is held as a closing celebration of the work of the Senior Class. The ritual and routine of holding these events define CHAD as an institution invested in creative and visual culture.

Figure 9. The Common Space at CHAD is Used Heavily

Note. In this picture the common space has been transformed into a runway for a student fashion show. Photograph by author, used with permission.

COLLEGE PLACEMENT

CHAD has a designated college guidance center and director. Art and Design colleges actively recruit CHAD students. CHAD has a graduation rate of 99%. Ninety-six percent of these graduates attend a four-year-college, with 62% attending an art or design college.

A small sampling of the colleges and universities CHAD alumni have attended include California College of the Arts, Cleveland Institute of Art, Community College of Philadelphia, Fashion Institute of Technology, Millersville University, Old Dominion University, Penn State University, Pratt Institute, Rhode Island School of Design, Syracuse University, Temple University, University of Maryland, and University of Pittsburgh.

Acceptance into college marks a distinction not only for the student but also for the student's family (see Figure 10). The family gains new socio-cultural funds as a result of their child attending college often outside Philadelphia and as far away as California.

Figure 10. The School's Culture Includes the Prominent Display of College Acceptance Letters

Note. Getting the students of CHAD into college is a priority. Toward that end, the acceptance letters are displayed publicly as forms of celebration and encouragement. Photograph by author, used with permission.

CHAD AS A MODEL FOR CHANGE

CHAD is part of a growing group of new schools that brand school identity with creativity and innovation, specific to architecture, design, and the built environment [2]. As Pink (2005) observed

> Although CHAD is a pioneer, it is not the only school of its kind. Miami's public school system boasts Design and Architecture Senior High School [DASH], New York City has the High School of Art and Design. Washington, D.C. has a charter elementary school called the Studio School. (p. 74)

Though these schools exist in urban areas, they are thriving. In spite of metropolitan cities' pervasive poverty yielding less money per pupil than suburban public schools, these design-focused schools provide positive change through innovative curriculum and distinct pedagogy. These schools are united in their mission to develop innovative thinkers prepared for college and professional lives. Each school aims to integrate design into curricula to provide learning activities that promote creativity and problem solving. Each school prepares students for college and a profession in, or informed by, its design-focused curriculum and culture. The resources each school has, the demographics specific to the local community each school serves, and the literal and figurative journey that children take to join these academic institutions are distinct. What is similar about the micro-cultures of these schools is how they employ design education to increase student achievement, secure college placement, and teach creativity and innovation.

While discussing the cultural paradigm shift from a world directed by "computer programmers who could crank code, lawyers who could craft contracts, MBAs who could crunch numbers" (p. 1) to one that is directed by "artists, inventors, designers, storytellers, caregivers, consolers, big picture thinkers" (p. 1), Pink (2005) noted

> The defining skills of the previous era—the 'left brain' capabilities that powered the Information Age—are necessary but no longer sufficient. And the capabilities we once disdained or thought frivolous—the 'right-brain' qualities of inventiveness, empathy, joyfulness, and meaning—increasingly will determine who flourishes and who flounders. For individuals, families, and organizations, professional success and personal fulfillment now require a whole new mind. (p. 3)

Schools like CHAD educate their students to use design thinking, which requires the active engagement of both sides of their brains.

These schools identify the design process as a distinct learning lens and teach students how to use this process to understand all subjects. Schools like CHAD use valid, reliable, and replicable tools for educational reform. These tools include innovative pedagogical practices and curricula, intentional teacher-to-teacher collaborative structures and teacher-to-student collaborative structures, real world partnerships, internships, externships, mentorships, and networks that are personally relevant to students' lives and professional choices.

Making a paradigm shift within the micro-culture of any given educational setting can be a difficult task. There can be many obstacles to making design a focus within the micro-cultures of a classroom, a school building, or even a school district. The first barrier to changing the status quo would be overcoming some peoples' narrow perception of what is meant by the word "design." Paola Antonelli, Senior Curator of Architecture and Design at the New York Museum of Modern Art addressed this matter when she said

> There are still people who believe that design is just about making things, people and places pretty. In truth, design has spread like gas to almost all facets of human activity, from science and education to politics and policymaking. For a simple reason: one of design's more fundamental tasks is to help people deal with change. (Antonelli, 2010, para. 1)

Though barriers exist to transitioning to a micro-culture like the one found at CHAD that is based on design, it is worth the effort. The CHAD model already demonstrates how students in such a micro-culture learn how to become creative problem solvers, reflective thinkers, and achievers. CHAD graduates are young people prepared to shape their future in a positive way.

The design-based field of architecture is a profession that centers on building the communities that make civilizations. This is an excellent cultural metaphor to present to students who are in the process of defining what role they will take in the world. Architecture, as a field of study, allows for the asking of essential questions. How will students be a constructive force in shaping their own environment and future? What tools will students use to develop the skills they will need for this future? What kind of community does the student want to be a part of in the future? What does this future look like? These questions resonate, because they are linked to the direct reality and immediacy of each student's life. Students can begin to answer these essential questions not only by imagining but also by doing. By solving design problems students become invested and engaged in positive, solution based, forward thinking.

If architecture can be used as a cultural metaphor for community or civilization then design has its own cultural metaphor, and that is service. To bring students into a culture of community and service is to be an agent of change. Design education has always presented profound platforms for debate that seeks to answer essential questions about form versus function, a classic binary. For the young student who may not know the differences among art, architecture, and design, making the statement that design is a service activity is a poignant way to show the difference. One such project is the annual AIA sponsored event called Spooktakular (see Figure 11).

Figure 11. CHAD Students and Local Design Professionals Engaging in a Design Charette

Note. Photograph by author, used with permission.

> During this event, design professionals and individuals collaborate with the students of CHAD to design and create a miniature Halloween streetscape in one day. Two weekends later the panels are then combined, to create a safe Spooky hallow for the nursery students at the CCTC (The Children’s Crisis Treatment Center). The Children's Crisis Treatment Center is an organization committed to assisting children and families cope with the impact of behavioral health issues, traumatic event and other challenges that have an effect on childhood development. (Spooktakular Charrette, 2010)

Through experiences such as the Spooktakular, CHAD students learn first hand to put the needs of others in the forefront of their thinking as they consider design options and work collaboratively in groups to achieve common goals.

When we design we think of others. We think in most cases of the client and the solutions the client seeks as well as the consumers' experience of said solutions. Design as service is a future-directed activity, invested in the betterment of the world for those around us for generations to come. In art we aim to express our own personal point of view. Good design requires the creator, the inventor, the engineer to go beyond the self and enter the realm of others to achieve the goal of making something useful or creating a solution to an identified problem in the form of products. Therefore good design requires service thinking. At a minimum, designers must consider factors that increase comfort and please the users by offering ergonomically effective, aesthetically pleasing products. Ideally, designers should think beyond the client and the consumer and consider how socially responsible and ecologically sustainable their products are for our planet and generations to come.

Design Projects within a high school curriculum provide instructors with opportunities to engage their students with higher order thinking concepts and essential questions generated within design units such as

- What production, technical, or material changes do you recommend for this challenge based on your own knowledge, experiences, or precedent studies you may have evaluated?
- What principle or element of design do you identify as the central feature of this designer or artist's repertoire and how is it effective? How might you use this feature in your own work?
- How does a solution answer or transcend all concerns of the client? What evidence is there of such trancendent solutions in your portfolio?

Higher order thinking at the levels of creating, evaluating, and analyzing is endemic to the design process (Overbaugh & Shultz, n.d.). The answering of essential questions and the application of those answers to an end product and an evaluation of that product by the user is the process that spirals throughout all units during four years at CHAD. This is a complete detail of the always spiraling, messy meandering intellectual loop called the design process, which is sometimes beautiful and elegant, sometimes messy and maddening.

CONCLUSION

The profound effect of a school like CHAD is that its very existence signifies change. Change is vital as we struggle to eradicate inequities that exist in student achievement, expenditure per pupil specific to school locale, and degree of participation as global citizens. Very grave inequities exist, but with a blueprint like the one used by the founders of CHAD, the circumstances of students' lives change and real, cumulative socio-economic change happens for cohorts of students. Design education sparks the change.

REFLECTIVE QUESTIONS

The following reflective questions are for educators to consider:

1. How can students with special needs benefit from an environment for creativity and design?
2. What elements of CHAD's culture are worthy of modeling in technology education programs?
3. What are the similarities of CHAD and a school focused on creativity and design in your region?
4. What are the differences of CHAD and a school focused on creativity and design in your region?
5. What portfolio guidelines would you establish to represent the oeuvre of student creativity in technology education courses?
6. How can design-based education support rigorous student learning outcomes as defined in many state curriculums?

FOOTNOTES

[1]For more information on Title I of the Elementary & Secondary Education Act, see the U.S. Department of Education website at http://www2.ed.gov/programs/titleiparta/index.html.

[2]There are several student-centered/personalized learning high school models to consider, such as *Big Picture Learning* http://www.bigpicture.org/, *The MET in Providence* http://www.bigpicture.org/2008/10/the-met-center-of-providence-and-newport-ri/, *Webster Middle School*, *Los Angeles* http://www.movoto.com/public-schools/ca/los-angeles/middle/062271003445-daniel-webster-middle-school/11330-graham-pl.htm,*The Center for Secondary School Redesign* http://www.cssr.us/index.htm, *NASSP/CSSR Breaking Rank School Showcase* http://www.cssr.us/showcase%20nassp%20feb2011.htm

REFERENCES

Antonelli, P. (2010, November 22). The world in 2036: Design takes over, says Paola Antonelli. *The Economist*. Retrieved from http://www.economist.com/node/17509367

Charter High School for Architecture + Design. (n.d., a). *History*. Retrieved from http://www.chadphila.org/history.html

Charter High School for Architecture + Design. (n.d., b). *Mission.* Retrieved from http://www.chadphila.org/mission.html

Charter High School for Architecture + Design. (n.d., c). *Why design as a basis for CHAD's curriculum?* Retrieved from http://www.chadphila.org/curriculum.html

Cross, N. (2000). *Engineering design methods: Strategies for product design* (3rd ed.). New York: John Wiley & Sons.

Culture. (2006). In *American Heritage Dictionary of the English Language* (4th ed.). Retrieved from http://dictionary.reference.com/browse/culture

Design style book master. (n.d.). Archives of the Charter High School for Architecture + Design, Philadelphia, PA.

Durkee, H. (2011). *Charter High School for Architecture + Design portfolio program 2011-2012*. Archives of the Charter High School for Architecture + Design, Philadelphia, PA.

Florida, R. (2002). *The rise of the creative class.* New York: Perseus Books.

KEA European Affairs. (2009, June). *The impact of culture on creativity:* A study prepared for the European Directorate-General for Education and Culture. *Retrieved from* http://www.keanet.eu/en/impactcreativityculture.html

Lubart, T. I. (1999). Creativity across cultures. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 339-350). New York: Cambridge University Press.

Neuliep, J. W. (2008*). Intercultural communication: A contextual approach* (4th ed.). Thousand Oaks, CA: Sage Publications.

Overbaugh, R. & Schultz, L. (n.d.). *Bloom's taxonomy*. Old Dominion University. Retrieved from http://www.odu.edu/educ/roverbau/Bloom/blooms_taxonomy.htm

Peace Corps. (1997). *Culture matters: The Peace Corps cross-cultural workbook*. Washington, DC: U.S. Government Printing Office. Retrieved from http://www.peacecorps.gov/multimedia/pdf/.../T0087_culturematters.pdf

Petroski, H. (1985). *To engineer is human: The role of failure in successful design*. New York: St. Martin's Press.

Pink, D. H. (2005). *A whole new mind: Why right-brainers will rule the future.* New York: Riverhead Books.

Roshan Cultural Heritage Institute. (2001). *Definition of culture*. Retrieved from http://www.roshan-institute.org/474552

Spooktacular charrette. (2010, October 9). *Plan Philly: Events*. Retrieved from http://planphilly.com/event/spooktacular-charrette

U.S. Department of Education. (2011). *Elementary & secondary education: Title I–Improving the academic achievement of the disadvantaged.* Retrieved from http://www2.ed.gov/policy/elsec/leg/esea02/pg1.html

Curriculum, Instruction, and Assessment for Creativity and Design

Chapter 10

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> For millions of years man's 'little red school house' was earth itself. Mankind was taught to react and to behave by the environment, disasters, and predators. But now we have replaced our 'natural enemies' with educators, and we try to learn from them. To brutally twist man away from his natural heritage of non-specialization in this way can only have brutal results. It is in the area of driving men into ever narrowing fields of specialization that the schools and universities have made their greatest mistakes. (Papanek, 2007, p. 112)

Many difficulties are involved with unraveling the deeply intertwined and contradictory triumvirate of curriculum, instruction and assessment that underpins education today. The connections and reciprocal nature of this triumvirate is central to the process of successfully integrating authentic creativity and design into technology education programs. Each component plays a critical role towards the inclusion of creativity and design and as integral unifying concepts.

In discussing this triumvirate Pellegrino (2006) clarified curriculum as content and objectives; instruction as pedagogy, processes and methods, and learning activities; and assessment as measurement of student achievement against stated levels of competence. These three interacting areas of educational endeavor must be synchronized for coherent education to occur. He also highlighted an important but under-appreciated capacity that supports the learning and application of knowledge and skills to new situations in creative and innovative ways. Pellegrino recognized this capacity as "adaptive expertise" (p. 2). This adaptive expertise is the capability that is exemplified in the acts of creativity and design.

Kimbell and Stables (2008) described design and technology capability as "the power to produce change and improvement in the made world" (p. 18). Competence, skill, and knowledge were viewed as inputs to this capability. They emphasised "Design & technology capability is procedural and in an educational setting can enable learners to organise and manage themselves through a project [task/assignment]" (p. 18).

CONTEMPORARY RESEARCH ON CURRICULUM, INSTRUCTION, AND ASSESSMENT

Pellegrino (2006) highlighted three important principles about learning and understanding that have implications for how we facilitate design capability and creativity in technology education. First, "students come to the classroom with preconceptions about how the world works which include beliefs and prior knowledge acquired through various experiences" (p. 3). Students may fail to understand new concepts if their initial understanding is not engaged. In providing opportunities to build on or challenge a student's initial understanding of a concept or theory their preexisting understanding (i.e., tacit knowledge) must be understood and tested. Second, "to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application" (p. 4). In mirroring Cross's (1982) designerly thought, the centrality of design thinking is reinforced by Pellegrino's description of developing competence as "the ability to plan a task, to notice patterns, to generate reasonable arguments and explanations, and to draw analogies to other problems" (p. 4). Students must have the opportunity to learn with understanding instead of the memorization of factual content. Kimbell and Stables (2008), noted that students "need to see knowledge and skills as resources for action rather than as ends in themselves" (p. 48). Pellegrino finished by highlighting "a 'metacognitive' approach to instruction [that] can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them" (2006, p. 5). This salient component, identified by Pellegrino as "adaptive expertise," (p. 2) can be taught. Students can improve understanding through these metacognitive (design) strategies of planning ahead, predicting outcomes, noting failures to comprehend, applying background knowledge, and using time wisely.

The variety of complex learning that supports the building and development of design capability, creativity, skills, knowledge, and understanding is difficult to manage and orchestrate. It requires a scientifically credible and shared understanding about cognition and learning. The teachers need to exhibit instructional flexibility and adaptive expertise. A shared model of cognition and learning can help to align our wayward triumvirate of curriculum, instruction, and assessment.

Pellegrino (2006) noted with irony that within the context of rising educational expectations for student learning the education system is driven by assessment criteria, which may seriously undermine high achievement standards and quality instructional practices. The reliance on those highly limiting, external accountability, standardized assessments of academic achievement could drive creativity out of the teaching arena and the most talented people away from the profession.

CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION CURRICULA

Within the ongoing international discourses in technology education, few topics create as much heated debate and fear within colleagues as “creativity” and the encouragement of student self-expression. What do we mean by creativity and how does it manifest in schools?

In a recent paper reviewing creativity in education, Spendlove (2005) indicated that in general, it is agreed that our creative capacity is what truly separates humans from other species. “Creativity, by its very nature is a complex topic of many facets—something that remains a ‘slippery concept’; that is difficult to pin down, nebulous and awkward to define” (p. 9).

Designing a curriculum that actively nurtures creativity requires teachers, working in teams, to develop a shared democratic definition and understanding of creativity. Mapping the opportunities for creativity within the curriculum and working towards developing appropriate instruction to support these skills enables students to become truly independent learners.

The idea of a democratic definition of creativity was proposed in the United Kingdom (UK) by the National Advisory Committee on Creative and Cultural Education (1999). “Creativity is imaginative activity fashioned so as to produce outcomes that are both original and of value” (p. 30). The Committee proposed four main features of creativity:

- *Using imagination*, often to make unusual connections or see unusual relationships between objects, ideas, or situations.
- *Pursuing purposes* through having targets and reasons for working, which can result in new purposes being discovered.
- *Being original* in comparison to their own work, the work of a small closed community such as peers or family, or uniquely original in comparison with those people working historically or currently in a field or discipline.
- *Judging value,* which demands critical evaluation and reflection; standing back and gaining an overview position.

Research on the thoughts and feelings of teachers towards the difficulties of promoting creativity in students indicates that teachers recognize creativity has a role to play in technology education; but they perceive this role as one that is subservient to the development of knowledge and skills. According to Davies (2000), teachers’ views are tempered not only by their personal interpretation of the elements of creativity but their own “self perceived” (p. 21) creative capacity. More importantly, they are concerned that attention to creativity may interfere with the achievement of assessment goals. Creativity is not perceived as being valued within assessment schemes. The active promotion of a student’s creativity requires "high risk" teaching strategies with a concern for a "long term view" of the learner's potential, a willingness to wait for results, and the confidence to act intuitively at times. Creativity is also difficult to evaluate and assess (Fryer, 1996), which adds to the difficulties teachers face when prioritizing creative work.

The negative and un-teachable view of creativity stems from a transmission or didactic model of teaching where the teacher disseminates information in a highly controlled and prescribed manner and summative assessment drives the learning process. Conversely, teachers who actively foster student creativity exemplify acting as facilitators, resource providers, guides, or coaches and provide the students with the freedom to make decisions and take ownership of their learning process and outcomes.

Jackson (2006) stated that creativity is linked to thinking conceptually, independently, originally, divergently, convergently, laterally, critically, and reflectively. Creative people imagine and cogitate in a non-linear manner with deconstruction and reconstruction. Creativity is associated with actions and activities such as solving problems, making sense, inventing, drawing, designing, observing, interpreting, producing, writing, combining, responding, and completing and sharing reflective journals that reveal thinking and emotions, collaborative work, and a stimulating challenge.

The process of curriculum design is also a creative process. The teacher as curriculum developer applies skill, knowledge, and imagination (adaptive expertise) to enhance the student's capacity to learn and think creatively. However, the location and perception of creativity within the curriculum remains a contentious issue with desirable creativity often found languishing on the periphery of the curriculum rather than at the centre.

STANDARDS FOR CREATIVITY AND DESIGN IN CURRICULA

Though struggling with legislation that enforces accountability-orientated assessments, school subject standards are continually being developed to be educationally relevant for students. Standards for technology education articulate the contributions and impact of creativity and design. The latest iterations of many standards of both national and international curricula have implicitly or explicitly included the metacognitive skills described within creativity and design.

Standards for Technological Literacy. Mirroring major national efforts to develop educational standards in a range of subject areas, the International Technology Education Association (ITEA; recently renamed the International Technology and Engineering Educators Association) with funding from the National Science Foundation presented to the profession a set of standards for technological literacy. *Standards for Technological Literacy* (*SfTL*; ITEA, 2000) stated "The goal is to produce students with a more *conceptual understanding* [emphasis added] of technology and its place in society, who can thus grasp and evaluate new bits of technology that they might never have seen before" (p. 4). The 20 standards were organized as the nature of technology, technology and society, *design*, abilities for a technological world, and the *designed* world.

ITEA (2003) enabled the implementation of these standards through the publication of companion guides such as *Advancing Excellence in Technological Literacy* (*AETL*). The *AETL* expanded on the stated goal by describing the characteristics of a technologically literate person:

> Technologically literate people are problem solvers who consider technological issues from different points of view and relate them to a variety of contexts. . . . Those who are technologically literate have the ability to use concepts from science, mathematics, social studies, language arts, and other content areas as tools for understanding and managing technological systems. Therefore, technologically literate people use a strong systems-oriented, *creative* [emphasis added], and productive approach to thinking about and solving technological problems. (International Technology Education Association, 2003, pp. 11-12)

Engineering by Design. These Engineering by Design (EbD) K-12 educational materials were based on *SfTL* for the study of Technology, Innovation, Design, and Engineering (TIDE). The STEM±Center for Teaching and Learning has developed and disseminated these materials, enhanced teachers, and conducted research to advance technological literacy through science, technology, engineering, and mathematics.

> Students in this program use hands on lessons to learn the concepts and roles of engineering, design, invention and innovation in creating technology systems that help make life easier and better. They learn to apply and transfer this knowledge to common, everyday problems. (ITEA, 2006, p. 13)

UK National Curriculum for Design and Technology. The importance of this National Curriculum (NC) educational program was stated as follows

> In design and technology pupils combine practical and technological skills with creative thinking to *design* [emphasis added] and make products and systems that meet human needs. They learn to use current technologies and consider the impact of future technological developments. They learn to *think creatively* [emphasis added] and intervene to improve the quality of life, solving problems as individuals and members of a team. Working in stimulating contexts that provide a range of opportunities and draw on the local ethos, community and wider world, pupils identify needs and opportunities. They respond with ideas, products and systems, challenging expectations where appropriate. They combine practical and intellectual skills with an understanding of aesthetic,

> technical, cultural, health, social, emotional, economic, industrial and environmental issues. As they do so, they evaluate present and past design and technology, and its uses and effects. Through design and technology pupils develop confidence in using practical skills and become discriminating users of products. They apply their creative thinking and learn to innovate. (Qualifications and Curriculum Authority, 2007, p. 51)

The English NC provided a framework used by all maintained schools to ensure that teaching and learning was balanced and consistent. This framework established

- the subjects taught
- the knowledge, skills, and understanding required in each subject
- standards or attainment targets . . . [and]
- how . . . [the] child's progress is assessed and reported. (Directgov, 2011, para. 2)

Directgov stated that several schools utilized the Qualifications and Curriculum Development Agency Schemes of Work to convert the NC's objectives into educational activities. Design and technology educators were free to plan and organize teaching and learning in the way that best met the needs of their pupils.

International Baccalaureate Organization. The International Baccalaureate Organization's (IBO) Diploma Programme for Design Technology stated

> The goal of technological knowledge is the improvement of the condition of humankind. The method of developing technological knowledge is *design* [emphasis added], but there is no single design method—it depends on the nature of the technological problem to be solved or the opportunity to be realized. The design method involves: the careful collection of data from many sources; a deep understanding of the design context; both convergent and divergent reasoning; *innovation and creativity* [emphasis added] in the suggestion of outcomes; and modeling skills (graphical and three-dimensional) in the representation of the technology.
>
> Technology is multidisciplinary, and so derives its knowledge from many sources. There is no set or defined body of technological knowledge. Relevant technological knowledge is only defined by the context of the problem or opportunity for which a technological solution is being sought. So designing, the methodology of technology, involves the seeking out of the knowledge that will facilitate a successful outcome. Some data and information may be

> collected and examined but later discarded because it does not progress the design process. During the guided collection of relevant knowledge, skills are developed that are applied to future technological problems. As the repertoire of skills becomes broader, individuals become more expert in understanding and developing technology. (International Baccalaureate Organization, 2007, p. 4)

Cross (1982) stated that this rationale for design technology expressed a common need to prepare students to live in a rapidly changing technological world. These statements articulated what it means to be a technologist/designer, rather than to be a scientist or an artist.

There seems to be a universal emphasis on learning to plan and produce solutions to technological problems, to become discriminating and informed users of technology, and to become innovative thinkers. The importance of learning by doing and problem solving is universally evident and understanding the underlying social, aesthetic, and environmental issues is essential.

PEDAGOGY FOR CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

As we transition from the Information Age to the Conceptual Age, Huitt (2007) noted that "the preparation of children and youth for success in the twenty-first century is a challenging and daunting task" (p. 7) made more difficult as "currently the dominant focus of schooling is on basic skills achievement" (p. 7). Children and youth will require additional attributes beyond those identified as important for the Information Age. In discussing the roles teachers play in promoting creativity (and design), Girl (1999) remarked "Teachers' beliefs and educational philosophy influence their instructional approach and hence, the pupils' learning. A teacher defines his/her role, and accordingly selects suitable pedagogical approaches, materials, and activities" (p. 42).

Various paradigms for the delivery of technology education exist. Wiggins and McTighe (as cited in Foothills School Division, 2009), in describing a model that enables a move away from the issues of covering the curriculum to creating curriculum and understanding, noted that "This approach requires teachers to structure what is addressed instructionally and in the curriculum around key ideas rather than try to *cover* content" (p. 1). This perspective attempts to tackle the two recurring issues in technology education of aimless coverage of content without context and isolated activities that engage learners without genuine purpose, thus creating an intellectual dislocation in the minds of the learners.

Wiggins and McTighe's (2005) focus was on student understanding and one of the main aims was designing the curriculum to engage students in inquiry and "uncovering" ideas. They exemplified this goal in their explanation of the "backward design model" as a process that is goal directed in which "the desired results of stage 1 [learning] dictate the nature of the assessment evidence needed in stage 2 [outcomes] and suggest the types of instruction and learning experiences planned in stage 3 [pedagogy]" (p. 56).

Mawson (2003), in looking beyond the design process, acknowledged that in technology education an idealized design process linked with project-centered methodology (design-make-appraise) has become one underpinning structure for technology education. This design project approach has become a distinctive pedagogical model of learning and teaching even though this concept is at odds with the reality of how professional designers work. A common misconception is in thinking that following a prescribed "design process"—whether linear or iterative—is all that is required to ensure that design capability and creative expertise, knowledge, and understanding are achieved. Design is about solving open-ended challenges and tasks for specific situations or needs—there being no apparent solutions at the beginning of the challenge—and dealing with the uncertainty inherent in that task has a profound impact on the nature of teaching.

Kimbell and Stables (2008) stated

> This task-centred, issues-rich view makes the learner an active participant in the process. In so doing, we are committed to a view of the teacher as being more a guide than an instructor. Teaching is therefore more about helping learners to find their way through a task rather then telling them what to do. (p. 32)

In clarifying this view these researchers

> do not see the teacher as primarily a transmitter of bodies of knowledge and skill, but rather a `coach' in the tricky arts of pursuing tasks effectively. This view of teaching arises from our procedural view of capability, and it also leads us to a pragmatic and predatory view about the role of knowledge and skills. (p. 34)

Girl (1999), in discussing teacher roles in promoting creativity, noted that teachers should adopt a multifaceted framework that allows them to work flexibly from a range of roles within the classroom. These roles are being shaped not only by new knowledge about how we learn but also by the growth of new technologies and its impact on the transmission of knowledge. There is recognition that teachers have to discard the uni-directory (hierarchical) role, as a transmitter of knowledge. Teachers need to be adaptable, exhibit their own adaptive expertise, and be comfortable in their various roles as learning facilitator, guide, mentor, resource, and evaluator as they apply contextually appropriate strategies and activities in supporting creativity and design capability.

Girl (1999) added that a rapid and complex development of information communication technologies provides students with an almost unlimited level of resources in knowledge and expertise. From teaching limited content knowledge teachers are required to shift their emphasis to leading pupils into exploring new knowledge and constructing innovative ideas. This intensive creative interaction between students and teachers requires the development of suitable environments, learning strategies, and appropriate content and assessment. Relating classroom learning to real life and posing challenging tasks that match pupils' competence produce interactions that allow teachers to determine student needs. Effective teaching in this situation elicits from students their pre-existing understanding about the subject and provides opportunities to build upon or challenge their initial understanding. Teachers and pupils acting as active information seekers and developers of learning foster a supportive classroom climate where creative thinking can flourish.

In this changing classroom environment teachers must master a wider range of roles to match the learning needs of the students (Girl, 1999). In their various roles, the teacher poses questions and encourages students to discover possible causes of a problem. The students are encouraged to generate solutions independently or in a group. Discussion and sharing are frequent activities between the teacher and the students. If students possess the ability to solve a problem, they are encouraged to find the solution independently. Students are encouraged to use various problem-solving strategies and evaluate their findings critically. The teacher-as-mentor style places a responsibility on learners to identify, communicate, and justify their intentions. A mentor is associated with the perception of the teacher as a senior who possesses rich experience in his/her areas of expertise and in life, and who believes in nurturing and cultivating lifelong creative thinkers. The students regard themselves as juniors in experience. The mentor is perceived as the role model. Information flows from the mentor to the students, from senior students to junior students, and among students of the same age. There are intensive and frequent interactions between the mentor and the students and among students under the same mentor. Teachers also provide support in the form of an expert resource for students in the practical application of skills and techniques. A teacher, acting as evaluator, is the gate keeper who administers a range of assessment procedures. Collectively, these teacher roles serve as modes of adaptive expertise and are applied in support of creativity and design capability within the classroom.

Panitz (1996) recommended that it behooves teachers to educate themselves about the myriad of techniques and philosophies that create interactive environments, such as collaborative and cooperative learning, where students take more responsibility for their own and peer learning. This knowledge empowers them to choose those methods that best fit the goals of creativity and design in technology education.

Barlex (2005) posited the value of design-based pedagogy by writing:

> It is designing that will develop pupils high level cognitive skills through which they will be able to handle uncertainty, seek out relevant knowledge, solve problems, make and justify decisions and communicate effectively. These are qualities that will serve young people well whatever career path they choose. (p. 7)

The roles of the 21st century technology teacher will be in understanding and applying student centered instructional approaches that help to develop design capability and creativity.Beyond their immediate time and compliance pressures teachers need to create time and space in their workloads to allow them to be creative and reflective practitioners. Reviewing and refining the teaching process is necessary for teachers to be able to meet the demands of the changing classroom.

CURRICULUM FOR CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

John Kerr, an educational philosopher, defined curriculum as "all the learning which is *planned and guided by the school* [emphasis added], whether it is carried on in groups or individually, inside or outside the school" (as quoted in Kelly, 2009, p. 12). Kerr viewed curriculum as a body of knowledge to be transmitted, and supported with the syllabus, that attempts to achieve certain ends in students. McLaren (2007) provided four categories that underpin the general inter-related nature of technological content: Conceptual knowledge (knowing that), procedural knowledge and capabilities (knowing how), competences and skills, and affective and societal knowledge. In discussing curriculum theory Smith (2000) posited curriculum as being either "a body of knowledge to be transmitted, an attempt to achieve certain ends in students – product, as process or as praxis" (para. 4). Smith went on to highlight the product form as the dominant mode of organizing education today. "Education is most often seen as a technical exercise. Objectives are set, a plan drawn up, then applied, and the outcomes (products) measured" (para. 9). Smith later concluded that teachers currently "operate within policy environments that prizes the productive and technical" (para. 53). This focus on the product of curriculum negates support for design capability and creativity as they are not valued or rewarded.

The recent evaluation of the national curriculum by the National Advisory Committee on Creative and Cultural Education (1999) has recommended an urgent semi-overhaul of the way creativity is encompassed within education. Creativity can be taught. Teachers can be creative in their own teaching; they can also promote the creative abilities of their pupils. The roles of teachers are to recognize young people's creative capacities and to provide the particular conditions in which they can be realized. However, curricula that actively support and engender creativity are difficult to find. Kimbell (2000) stated

> Risk, confidence and trust are interrelated factors. Creative acts are inherently risky. Only confident students will take creative risks and only if they trust their teachers. Only confident teachers will take creative risks, and only if they trust that those in authority over them value what they are doing. (p. 210)

Rasinen (2003) studied the education curricula of Australia, England, France, The Netherlands, Sweden, and United States to establish a theoretical basis for planning a national curriculum framework for technology education in Finland. He stated that although the essentials were discovered, a single model could not be recognized. These countries are separated not only by geographical location but by distinct cultures with similar features in their curricular objectives, methods, and content.

Technological literacy is a developmental goal, and design capability and creativity are implicitly and explicitly included in the technology education programs for all of the countries studied by Rasinen (2003). The roles of science and technology in society are clarified, with the overall methodology focused on experiences that engage and challenge the students in planning, making, evaluating, social/moral/ethical thinking, innovativeness, awareness, flexibility, and entrepreneurship. Subject content in each country included systems and structures of technology, professions in technology and industry, safety practices, ergonomics, design, construction techniques, assessment practices, the role and history of technological development, problem-solving strategies, and evaluating and valuing the relationship between society and nature.

Garmire and Pearson (2006) compared technology-related capability curricula for the United Kingdom and the United States while examining approaches to assess technological literacy. Their findings included

> The British design and technology curriculum centers on doing 'authentic' design tasks, activities that represent a believable and—for the student—meaningful challenge. . . . From an assessment standpoint, performance . . . is of primary interest . . . Specific knowledge . . . capabilities . . . ways of critical thinking and decision-making are relevant only insofar as they advance a student's design work. . . . However, there is considerable interest in how students *use* their knowledge, whether they recognize when they are missing key information and how skillfully they gather new data. . . .
>
> In contrast, in the United States, curriculum in technology, as in most subjects, is centered on the acquisition of specific knowledge and skills. . . . Assessments are based mostly on content standards, which represent expert judgments about the most important knowledge and skills for students to master.

> The committee [on Assessing Technological Literacy] found a great deal to commend the British approach to assessing design-related thinking. For one thing, the design-centered method much more closely mimics the process of technology development in the real world and seems likely to promote higher order thinking. . . . The ideas that design always involves some degree of uncertainty and that no human-designed product is without shortcomings are more likely to be understood at a deeper level by someone who has engaged in an authentic design challenge than by someone who has not. (pp. 107-110)

However, Spendlove (2005) noted

> The location of creativity within the school curriculum remains a contentious area of discussion as there is a tendency to locate creative activity merely within the arts. Most educators would acknowledge that this is a naïve perception yet the pragmatics of education, which often take precedence, mean that although desirable, creativity is often marginalized and remains on the periphery rather than at the centre of the curriculum - even in D&T. (p. 9)

The project-centered, metacognitive pedagogy of the technology curriculum offers a unique educational platform for encouraging and developing creativity and design capability in students. Kimbell and Perry (2001) of the UK Engineering Council, identified five key stages:

- Unpacking the wickedness of tasks,
- Identifying values,
- Creative exploration,
- Modelling futures, and
- Managing complexity and uncertainty. (pp. 5-6)

Kimbell and Perry (2001) stated

> Students are challenged to learn how to unpack the task not only to reveal its complexity but also to enable them to identify and focus on the central issues that need to be addressed. . . . Good design practice . . . seeks to identify the stakeholders in any task and make their values explicit from the outset. . . . Teachers can exploit this diversity to illuminate the value issues for students. (p. 5)

One side of creative exploration involves "conceiving and planning what does not yet exist. . . . Early exploratory thinking is inevitable (and properly) fuzzy, as students speculate and imagine multiple 'what-if's'" (p. 6). The other side of creativity is idea modeling that enables students to visualize and better understand their ideas and judge its consequences. Students are challenged to continually model their ideas enabling them to make informed judgments before committing themselves to a solution. The authors went on to say that

> The closer this model can simulate the ultimate reality, the better they will be able to judge its impact in a new reality. And thereby, . . . better able to manage the risk that is inherent in implementing the new and the innovative. . . . They need to be holistic integrative thinkers whilst managing the messy and often contradictory strands of thought within a project. (p. 6)

Through the demands of our knowledge based economy, curriculum design has transitioned from a traditional narrow subject-content base to a broader learner-experience base required for a future work force. Huitt (2007) stated "Reliance on [a] mechanistic, reductionistic paradigm to determine needs and curriculum standards leads to a centralized, standardized approach that is inadequate to meet the demands of the twenty-first century" (p. 9). Kimbell (2000) stated his recommendation to meet the challenge of our changing environment:

> To support the creative performance of our students in design and technology we need teachers with artistry; who have the confidence to allow their students to take ownership of their work and develop it in unexpected ways; who have the subtlety to provide the emotional support that students will desperately need; and who can (at the same time) provide the appropriate level of intellectual challenge and questioning to help the students develop their ideas. (p. 210)

ASSESSING CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

Educational assessment values what can be measured. The continued focus on traditional summative assessment of learning continues to dominate the viewpoints of both students and teachers. When the final grade or test scores are valued highly, teachers tend to teach to the test by training and coaching students in exam-preparation.

Many teachers in the United States point to the current No Child Left Behind (NCLB) legislation with a view of assessment being restrictive and designed principally to function as a means of accountability, or ranking, or of certifying a level of aptitude. These practices negate the students' freedom to be creative and minimize the benefits of designerly thinking and doing. The value of creativity and design capability is often undermined when students do not see its assessment within the standardized tests that they are required to complete.

Kimbell (2002) indicated therefore "teachers are encouraging youngsters to produce work that is formulaic, traditional, individual, technical, and mundane. We measure what is measurable and that typically leaves innovation and creativity out in the cold" (p. 173).

Being creative requires risk from both teacher and student alike. However, syllabi and curricula assessment guidelines have given little room for risk-taking as they are required to produce specific physical evidence and documentation to gain a successful grade. Teachers may shy away from student directed design tasks due to the feeling that it would limit their ability to meet the prescribed assessment criteria. Thus, judging student performance using inflexible assessment strategies can have a negative impact in an environment where dealing with uncertainty and having a flexible approach is valued.

Clearly, assessment aimed at determining a learner's creative capacities, design capabilities, and technological knowledge and understanding is challenging. The various difficulties of assessing thought in action, as required for technological capability, lie with the complexity of communicating creative (and designerly) thinking in a way that it can be witnessed, evidenced, and interpreted as such by others. It demands that creativity and designerly thought be displayed or recorded in a form that can be grasped by others to judge (McLaren, 2007).

In her introduction to discussing a theory of educational assessment (Gipps, 1994) identified "a paradigm shift, from psychometrics to a broader model of educational assessment, from a testing and examination culture to an assessment culture" (p. 1). She explained that assessment has

> taken on a high profile and is required to achieve a wide range of purposes: . . . support teaching and learning, provide information about pupils, teachers, and schools, act as a selection and certificating device, [serve] as an accountability procedure, and drive curriculum and teaching. (p. 1)

Reflecting current understanding about how we learn, McLaren (2007) recognized three purposes of attainment: assessment for learning, assessment as learning, and assessment of learning. Assessment that is both for and as learning requires formative strategies while assessment of learning employs summative measurement instrumentation.

Moreland, Jones, and Barlex (2008) have supported the use of summative assessment to make effective summations of student learning. Teachers should plan a scheme to employ summative assessment by placing appropriate values and focus on the technological, conceptual, and procedural understanding and skills. These summative assessments can be based on how effective the student has been in bringing together all aspects of the task.

As previously stated, McLaren (2007) posited the application of formative assessment strategies and techniques *for* learning and *as* learning. Assessment for learning involves a learner centered approach in which learning intentions and goals are shared. Moreland, Jones, and Barlex (2008) asserted

> Assessment for learning is any assessment for which the first priority in its design and practice is to serve the purpose of promoting student’s learning. It thus differs from assessment designed primarily to serve the purposes of accountability, or of ranking, or of certifying competence. (Introduction, para. 1)

Assessment as learning involves teachers and learners reflecting upon those intentions. This process also involves teachers supporting students in self and peer assessment towards their understanding of how they learn to learn (McLaren, 2007). Formative assessment applies methods to recognize the processes of learning that have taken place and encourages students to refine their learning. Assessment for learning should be continuous and embedded as an essential part of teaching and learning. It involves sharing learning goals with pupils and aims to help pupils to know and recognize the standards being pursued. It involves pupils in self and peer assessment and provides feedback that leads to pupils recognizing their next steps and how to take them. Assessment also involves both teacher and pupils reviewing and reflecting on assessment data (Moreland, Jones, & Barlex, 2008)**.**

McLaren (2007) reported that applying a range of short, medium, and long term formative assessment strategies can raise student attainment of creativity, design thinking, the application of technological knowledge, practical competence, and skills. The application of formative assessment strategies, for, as, and of learning, is heavily reliant upon a teacher’s personal pedagogic and content knowledge, technological capability, and the ability to clearly articulate the procedural and conceptual learning outcomes of tasks that are devised for classroom experience. A technology teacher's uncertainty about the value and purpose of creativity, design thinking or any technological activity, can result in low teacher confidence and low quality teaching, which has a knock-on effect (a secondary consequence) in the usefulness and consistency of assessment and a negligible impact upon a learner's progress.

Moreland, Jones, and Barlex (2008) discussed five principles to facilitate assessment for learning in design. These principles are as follows:

- begin with recognizing what students already know and can do,
- actively engage the students in the process of learning,
- enable students to talk about their technological ideas with others,
- provide a clear understanding of the intention of what students are to learn, and
- give genuine feedback to the students on how to improve.

Utilizing these five principles of learning, assessment can be planned for learning promotion, questioning and dialogue, feedback, self and peer assessment, and the formative use of summative assessment.

Formative assessment for creativity and design requires clear goal setting. Moreland, Jones and Barlex (2008) suggested grouping goals into conceptual, procedural, societal, and technical categories. Through these goals, teachers can propose clearly defined activities that contribute to the learner meeting those goals. By having a clear understanding of the proposed learning goals, outcomes, and skills—focused on actual design thinking, creativity or specific technological concepts—that are pertinent to the task, assessment becomes clearly focused on allowing precise feedback about how the learner can progress. Such feedback and guidance involves a higher degree of classroom dialogue in helping the learner to develop an understanding of the goals within the task set. Formative in-class teacher and student dialogue revolves around thinking and talking about design ideas, comparing and contrasting technologies, recognizing concepts, categorizing and grouping examples of technology, making predictions about design and technology activities, engaging students in emerging problems, and working alongside the student during design and technology activities.

Assessment of technology education in general, and design capability and creativity in particular, is complex and has a significant influence upon classroom pedagogy. Prevailing modes of assessment appear to reinforce outmoded notions of what is of value, and what and how to measure what has been learnt. These notions have profound consequences for young people who are confronted by an employment market based on a knowledge economy that demands flexibility, adaptability, and breadth of discipline while rewarding teamwork, communication, and problem-solving skills. These are the foundation stones of design capability, creativity, and technological competence. Technology students need to be empowered citizens who are confident working alone or in teams; capable of taking on a variety of tasks or projects from inception to delivery, integrating knowledge and understanding from different fields; and creatively improving the made world whilst optimizing and expressing the values of society in effective new products and applications.

To support such development, evidence cannot be sourced from one format alone. Assessment should be drawn from multiple sources to support conclusions regarding a learner's intellectual functioning and creative design capability and technological performance.

EDUCATING STUDENTS FOR THE CONCEPTUAL AGE

Pink (2006) declared

> We are moving from an economy and a society built on the logical, linear, computerlike capabilities of the Information Age to an economy and a society built on the inventive, empathic, big-picture capabilities of what's rising in its place, the Conceptual Age. (pp. 1-2)

He continued to avow that "now we're progressing . . . to a society of creators and empathizers, of pattern recognizers and meaning makers" (p. 50).

Huitt (2007) summarized the Conceptual Age as

> an infusion of values into economic activity with consumers having ubiquitous high-speed access to information and living in abundance. Workers and businesses are simultaneously coping with the pressures from globalization, especially new-found economic powers in Asia, and increasingly sophisticated processes of automation capable of delivering on those demands. (p. 5)

To respond to the need for fast-paced innovation decisions about how to cope with these pressures within organizations, Huitt (2007) highlighted two important issues:

1. What are the knowledge, attitudes, and skills necessary for success in this new age?
2. How should schools and education be transformed to address these changes?

Huitt (2007) affirmed that a primary function of schooling is to prepare students for their successful step into the adult world of work in the 21st century. They need to have the knowledge and skills to benefit from the rapid change of technological development created largely by the personal computer and open access via the Internet to an ever-increasing body of information. Educators have focused on developing curriculum, delivering instruction, and assessing their students for this knowledge economy.

To flourish in this age, Pink (2006) proposed a high concept and high touch strategy:

> We'll need to supplement our well-developed high-tech abilities with abilities that are high concept and high touch. . . . high concept involves the ability to create artistic and emotional beauty, to detect patterns and opportunities, to craft a satisfying narrative, and to combine seemingly unrelated ideas into a novel invention. High touch involves the ability to empathize, to understand the subtleties of human interaction, to find joy in one's self and to elicit it in others, and to stretch beyond the quotidian, in pursuit of purpose and meaning. (pp. 51-52)

Pink’s (2005) description of what is needed to flourish in the Conceptual Age speaks to the potential of the neglected “third culture” of education, which Cross (1982) identified as “designerly ways of knowing” (p. 221). In proposing design as a discipline within general education, Cross stated “design in general education is *not* primarily a preparation for a career, *nor* is it primarily a training in useful productive skills for ‘doing and making’ in industry. It must be defined in terms of the *intrinsic values* of education” (p. 223).

Therefore, learners must possess attributes beyond those that have been required for the Information Age. Pink (2005) described several attributes that would qualify as Cross’s intrinsic values of design that could be gleaned from technology education. The development of *empathy* must accompany logic and critical thinking. The ability to tell a *story* is needed beyond just presenting an argument. Focusing on *play* directs attention to process and a willingness to take risks rather than the outcome or product. *Design* is becomng crucial economically as well as personally rewarding towards creating emotionally engaging products.

It also develops abilities in recognizing and combining pieces through analysis and synthesis.

The rapidly changing economic, environmental, technological, and social contexts in the 21st century makes the previous mechanistic paradigm to codify needs and curriculum standards inadequate. A new paradigm of curriculum, instruction, and assessment such as Cross's designerly ways of thinking and doing is warranted in preparing students for living and working in a Conceptual Age.

CREATIVITY AND DESIGN THINKING FOR EMPLOYMENT

Within the executive summary of *Tough Choices or Tough Times* (National Center on Education and the Economy, 2007), the New Commission on the Skills of the American Workforce discussed a range of educational issues that have conspired towards the slow decline of the United States in the world's educational measurements. The summary acknowledged that the education and training systems currently maintained were built to service another era and are woefully inadequate. The Commission then proposed a systematic change in the nature of the education system in the United States. The proposed system would not be a "one size fits all" design; however, having its own integrity it can be implemented in many ways.

The Commission acknowledged "those countries that produce the most important new products and services can capture a premium in world markets that will enable them to pay high wages to their citizens" (p. xviii). The maintenance of a worldwide technological lead by the U.S., however, depends upon a deep vein of creativity by people who are able to imagine products and systems that do not yet exist (National Center on Education and the Economy, 2007). A pertinent example is the Apple company's application of a range of emerging technologies and interactive software to develop whole new market segments through the introduction of the iPod, iTouch, and iPhone, which are indispensable tools of the information age.

> The best employers the world over will be looking for the most competent, most creative, and most innovative people on the face of the earth and will be willing to pay them top dollar for their services. This [scenario] will be true not just for the top professionals and managers, but up and down the length and breadth

> of the workforce. (National Center on Education and the Economy, 2007, p. xviii)

Thus, having strong skills in all three of Cross's (1982) cultures of education, not just in the sciences and the humanities but in creativity and design capability as well, will be essential and an indispensable foundation for students entering the workforce of the 21st century.

Fundamental changes are proposed to develop standards, assessments, and curriculum in education that reflect today's needs and tomorrow's requirements. A design discipline within the school curriculum would bridge the academic (science and humanities) with the practical learning by doing (designerly). Theory, drawing on the humanities, sciences, and design would be applied to produce tangible systems and products that respond to the human needs of the world. Students preparing for the 21st century workforce would need to become "comfortable with ideas and abstractions, good at both analysis and synthesis, creative and innovative, self-disciplined and well organized" (National Center on Education and the Economy, 2007, pp. xviii-xix), quick learners, and team members who "have the flexibility to adapt quickly to frequent changes in the labor market as the shifts in the economy become ever faster and more dramatic" (National Center on Education and the Economy, 2007, p. xix).

CONCLUSIONS AND SUMMARY

The historic split between the mind and the hand in education has had fundamental repercussions for successive generations of citizens regarding how they perceived their identity, status, and value in society. The continuing rapid technological development, which is indicative of the Information Age, is now demanding a synthesis of these two disparate areas of education as we approach a new paradigm shift into Pink's (2005) Conceptual Age. The NCLB legislation, regardless of the expensive short-term gains in attainment in a narrow group of subjects, has exacerbated this split.

Shannon (1990) pointed out that people who design the future will live in an age of cultural pluralism in which dangerous social and economic inequalities complicate the task of identifying needs, motivating people, and achieving social census. Before learning and productive living can occur, people must be motivated. Motivation depends on recognizing that something is important and that it is relevant. Recognizing relevance depends upon identity. If you do not know who you are, you will not know what is relevant to you. Many young people do not know who they are, and so do not know that education is relevant. Our present educational system unfortunately offers little help in evoking identity or in making education relevant.

As a general synthesizing concept, a discipline of design that fosters both creativity and designerly thought should be the keystone of technology education. Cross (1982) provides three areas of justification through identifying aspects of designerly ways of knowing for the inclusion of design in general education:

- Design develops innate abilities in solving real-world, ill-defined problems.
- Design sustains cognitive development in the concrete/iconic modes of cognition.
- Design offers opportunities for development of a wide range of abilities in nonverbal thought and communication. (p. 226)

Within the range of syllabi and standard descriptions of knowledge and skills for the study of technology covered in this chapter there has been a clear articulation both explicitly and implicitly of the importance of creativity and design. A change in the pursuit of knowledge has been realized as being task centred and being accessed by students on a need to know basis. A fundamental shift in how teachers operate within the classroom also has resulted in the teacher being known as “The `guide on the side' more than the `sage on the stage'” (Kimbell & Stables, 2007, p. 32). Valuing design capability and creativity within the technological activity (thought in action) can only be authentically supported through a mix of flexible short, medium, and long term formative assessment strategies. Assessment has a heavy influence upon pedagogy in that it shapes teaching and learning; assessment that does not value creativity or the discipline of design negates a range of knowledge and skills that our students require to survive in the Conceptual Age.

As a practitioner of design and technology education to a varied school population from grades six through twelve, I am challenged by the overwhelming weight of the task ahead. When reflecting upon the what, why, when, and how of the curriculum I follow, the practice I exhibit, and the assessments I apply, I am quick to point out that what sounds great in theory is often jeopardized in classroom practice. It is a demanding task to stay current with technological changes and be pedagogically relevant. The world in which I started teaching does not remotely resemble the one I currently inhabit; the one consistent theme, however, has been rapid change and the uncertainty it engenders.

How successful have I been in articulating how creativity and design can be promoted through curriculum, instruction, and assessment? Your response will be shaped by your own pedagogical perspective and view of yourself as an educator. Dealing with the typical day-to-day distractions that all teachers must address often takes me away from my primary occupation. As a result, it has been difficult to personally interrogate each of the various connections of this triumvirate beyond the views of those whose thoughts and words I have borrowed to create this narrative. The opportunity to undertake some professional reflection, as in most cases, raises more questions than answers. The one thought I keep returning to is what type of student am I trying to create? Teachers require the tools to help students develop authentic interdependent thinking and learning that reaches beyond the traditional subject knowledge silos, developing creative students who display adaptive expertise (design capability) as a matter of course. It is not about the thing it is about the thinking and as far as Mr. Papanek's little red schoolhouse is concerned, in a conceptual world there is no schoolhouse.

REFLECTIVE QUESTIONS

1. What is the goal of creativity and design capability in technology education?
2. What type of workforce or citizen designers should technology educators create?
3. Based upon desired educational outcomes, what kind of cultural, social, and environmental pedagogy is needed to prepare students for active participation in a Conceptual Age?
4. Based upon the perspectives of design as a discipline, Cross's missing link of a third educational culture, Kimbell and Stable's view of capability, and Pellegrino's development of an adaptive expertise, what kinds of unique creativity and design learning experiences can technology education contribute to the school curriculum?
5. Based on the need for self-rigor to balance the procedural with the conceptual, what are the criteria for a good technology education curriculum? And, how then could this curriculum be assessed?

REFERENCES

Barlex, D. (2005). *The centrality of designing—an emerging realization from three curriculum projects* [Submission for PATT 15]. Brunel University, England. Retrieved from http://www.iteaconnect.org/Conference/PATT/PATT15/Barlex.pdf

Cross, N. (1982, October). Designerly ways of knowing. *Design Studies, 3*(4), 221-227. Retrieved from http://design.open.ac.uk/cross/documents/DesignerlyWaysofKnowing.pdf

Davies, T. (2000). Confidence! Its role in the creative teaching and learning of design and technology. *Journal of Technology Education, 12*(1), 18-31. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v12n1/pdf/davies.pdf

Directgov. (2011, July). *Understanding the National Curriculum* [UK government newsgroup post]. Retrieved from http://www.direct.gov.uk/en/Parents/Schoolslearninganddevelopment/ExamsTestsAndTheCurriculum/DG_4016665

Foothills School Division. (2009). Supporting handbook for assessment, evaluation, and reporting of student learning: A toolbox for educators. Alberta, Canada. Retrieved from http://www.fsd38.ab.ca/uploads/documents/Supporting_Handbook.pdf

Fryer, M. (1996). *Creative teaching and learning*. London, UK: Paul Chapman.

Garmire, E. & Pearson, G. (Eds.). (2006) *Tech tally—Approaches to assessing technological literacy*. Washington, DC: National Academies Press.

Gipps, C. V. (1994) Beyond testing: Towards a theory of educational assessment. Washington, DC: Falmer.

Girl, T. A. (1999). Teacher roles in promoting creativity. *Teaching and Learning, 19*(2), 42-51. Retrived from http://repository.nie.edu.sg/jspui/bitstream/10497/381/1/TL-19-2-42.pdf

Huitt, W. (2007, October). *Success in the conceptual age: Another paradigm shift*. Paper presented at the 32nd annual meeting of the Georgia Educational Research Association, Savannah, GA. Retrieved from http://www.edpsycinteractive.org/papers/conceptual-age.pdf

International Baccalaureate Organization. (2007). *Design technology guide.* Cardiff, Wales: Author. Retrieved from http://intranet.wellingtoncollege.org.uk/resource.aspx?id=215827

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: Author. Retrieved from http://www.iteaconnect.org/TAA/Publications/TAA_Publications.html

International Technology Education Association. (2003). *Advancing excellence in technological literacy: Student assessment, professional development, and program standards.* Reston, VA: Author. Retrieved from http://www.iteaconnect.org/TAA/Publications/TAA_Publications.html

International Technology Education Association. (2006). *Engineering By Design.* Reston: Author. Retrived from http://www.sde.ct.gov/sde/lib/sde/PDF/Curriculum/teched/EbDProgramGuideV52_06.pdf

Jackson, N. (2006, January). *Developing and valuing students' creativity; a new role for personal development planning?* Survey Centre for Excellence in Professional Training and Education, University of Surrey, UK. Retrieved from http://www.surrey.ac.uk/search/?cx=004166461246994000727%3Ap3yvcjwjr3o&cof=FORID%3A11&ie=UTF-8&q=Norman+Jackson+&x=9&y=8#990

Kelly, A. V. (2009) *The curriculum: Theory and practice* (6th ed.), London: Sage.

Kimbell, R. & Perry, D. (2001). *Design and technology in a knowledge economy.* London: Engineering Council.

Kimbell, R. (2000). Creativity in crisis. *Journal of Design & Technology Education, 5*(3), 206-211.

Kimbell, R. (2002). Assessing design innovation: The famous five and the terrible two. *Journal of Design and Technology Education, 7*(3), 172-180. Retrieved from http://jil.lboro.ac.uk/ojs/index.php/JDTE/article/view/366/344

Kimbell, R., & Stables, K. (2008). *Researching design learning: Issues and findings from two decades of research and development.* Secaucus, NJ: Springer Science + Business Media B.V.

Mawson, B. (2003). Beyond "the design process": An alternative pedagogy for technology education. *International Journal of Technology and Design Education, 13*(2), 117-128.

McLaren, S. V. (2007). An international overview of assessment issues in technology education: Disentangling the influences, confusion and complexities. *Design and Technology Education: An International Journal, 12*(2), 10-24. Retrieved from http://strathprints.strath.ac.uk/3969/1/strathprints003969.pdf

Moreland, J., Jones, A., & Barlex, D. (2008). *Design and technology inside the black box—Asessment for learning in the design and technology classroom.* London: GL Assessment.

National Advisory Committee on Creative and Cultural Education. (1999, May). *All our futures: Creativity, cultural and education* (Report to the Secretary of State for Education and Employment & the Secretary of State for Culture, Media and Sport, UK). Retrieved from http://sirkenrobinson.com/skr/pdf/allourfutures.pdf

National Center on Education and the Economy. (2007). *Tough choices or tough times—the report of the new commission on the skills of the American workforce*. San Francisco: Jossey-Bass. Retrieved from http://www.skillscommission.org

Panitz, T. (1996). Re: Collaborative learning versus cooperative learning [Online forum comment]. Retrieved from http://www.psy.gla.ac.uk/~steve/pr/ted.orig

Papanek, V. (2007). *Design for the real world: Human ecology and social change*. Retrieved from http://playpen.icomtek.csir.co.za/~acdc/education/Dr_Anvind_Gupa/Learners_Library_7_March_2007/Resources/books/designvictor.pdf.

Pellegrino, J. W. (2006, November). *Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests* (A paper commissioned by the National Center on Education and the Economy for the New Commission on the Skills of the American Workforce). Retrieved from http://teacherlearner.com/activelearning_media/Pellegrino-Redesigning.pdf

Pink, D. (2005, February). Revenge of the right brain. *Wired*, 13.02. Retrieved from http://www.wired.com/wired/archive/13.02/brain.html

Pink, D. H. (2006). *A whole new mind: Why right-brainers will rule the future*. New York: Riverhead.

Qualifications and Curriculum Authority. (2007). *Design and technology—programme of study for key stage 3 and attainment target* (Extract from The National Curriculum). Retrieved from http://curriculum.qcda.gov.uk/uploads/QCA-07-3331-pDesignTech3_tcm8-398.pdf

Rasinen, A. (2003). An analysis of the technology education curriculum of six countries. *Journal of Technology Education, 15*(1), 31-47. Retrieved from http://scholar.lib.vt.edu/ejournals/JTE/v15n1/pdf/rasinen.pdf

Shannon, M. J. (1990). Toward a rationale for public design education. *Design Issues, 7*(1), 29-41. Retrieved from http://www.jstor.org/pss/1511469

Smith, M. K. (2000). *Curriculum theory and practice: The encyclopaedia of informal education.* Retrieved from www.infed.org/biblio/b-curric.htm.

Spendlove, D. (2005). Creativity in education: A review. *Design and Technology Education: An International Journal. 10*(2), 9-18. Retrieved from http://ojs.lboro.ac.uk/ojs/index.php/DATE/article/view/122

Wiggins, G. & McTighe, J. (2005). *Understanding by design* (2nd ed.). Alexandria, VA: ASCD

Professional Development of Teachers to Support Creativity and Design in the Technology and Engineering Education Classroom

Chapter 11

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References to creativity and design can be found in a number of the historical technology education curriculum documents from the 20th century, although in some cases these references centered on the learning of drafting skills (e.g., Hostetler, 1960). One can trace a more focused emphasis on creativity and design beginning in the late 1980s, through conference presentations (e.g., Rye, 1988) and articles (e.g., Hutchinson & Hutchinson, 1991; Pedras & Braukmann, 1990); although in those days, a term more often employed was "problem-solving." In spite of what might be considered deep roots for inclusion of design in the technology education curriculum, its use as a fundamental instructional approach in technology education classrooms is still not necessarily widespread today, and there is continuing emphasis placed on development of technical drawing skills as "design" (Warner & Morford, 2004). Nevertheless, a confluence of interest in engineering design, in designing as an instructional strategy, and in design ability as a curriculum goal has resulted in the need for a more targeted and mature approach to design education in the technology education classroom. Therefore, efforts such as this Yearbook, and examinations of the professional development needs of teachers, are necessary for identifying strategies to promote creativity and design in technology education.

OVERVIEW OF PROFESSIONAL DEVELOPMENT ISSUES IN DESIGN AND TECHNOLOGY AND ENGINEERING EDUCATION

With regard to teacher professional development in the use of design in the technology classroom, three primary goals can be identified. These goals include

- promoting teacher *understanding* of design processes,
- promoting teacher *competence* with applying design processes in the classroom, and
- linking design activity with curriculum goals and standards.

When thinking about the structure of professional development experiences in design education, it will be helpful to acknowledge and consider some of the issues—and challenges—that are present.

The Challenge of Integrating Authentic Design Activities. To the extent that technology education at the K-12 level is representative of, or serves as the precursor to, engineering education at the collegiate level, we can look to the latter for insights into the technology education curriculum. Dym, Agogino, Eris, Frey, and Leifer (2005) observe that, in spite of calls for curriculum modifications, design is still not effectively integrated into university-level engineering education courses. Senior capstone design courses are prevalent, and some institutions have put in place freshman-level design courses, sometimes called “cornerstone design courses” (p. 103). On the whole, however, *effective* design education in engineering programs remains somewhat elusive, because it is difficult to mirror the ways that designers think and act in practice:

> Design thinking reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively on teams in a social process, and “speaking” several languages with each other (and to themselves). (Dym et al., 2005, p. 104)

The cross-disciplinary thinking that is common in design practice can be hard to replicate in classroom settings.

When attempting to develop design activities that might be considered authentic, it is important to select those activities that are reflective of actual design practice; to address design challenges that are meaningful both to students and to society; and to focus on the broader skills and abilities to be developed through classroom design activity.

Examining the literature on creativity in both educational and organizational settings can be beneficial to technology teachers interested in developing the creative design potential of their students. There is a growing body of work on creativity in organizations, due to the belief that creativity is necessary for product breakthroughs and to remain competitive, as well as to address pressing societal issues. This belief is true in established corporations, for individual entrepreneurs, and in governmental and educational settings (Cropley & Cropley, 2007; Robinson, 1999; Styhre & Sundgren, 2005). For teachers, particularly in technological fields, it is helpful and necessary to keep sight of the reasons why we promote particular skills and abilities, including creative problem solving.

The Challenge of Ensuring that Students Have Requisite Knowledge and Skills. Dym, et al. (2005) noted that students who enter college-level engineering courses have generally had good exposure to analytical courses such as mathematics and science, but little exposure to design and open-ended problem-solving activity, which is a shortcoming also noted in technology education contexts (John Belt, personal communication, July 10, 2010). At the middle and high school levels, moreover, students are likely to have more limited content knowledge, analytical skills, graphic and verbal communication abilities, and production skills. The need to address development of these types of abilities in students must be considered in addition to providing opportunities for meaningful, open-ended design activity.

Sternberg and Williams (1996), among others, stressed that effective creativity involves much more than just generating new ideas. Their conception of creative work described a requisite balance of “synthetic ability,” or the ability to make connections and generate unique ideas; “analytic ability,” or the capacity to analyze and evaluate ideas to determine those ideas most fruitful for pursuit; and “practical ability,” or the ability to translate an idea into something that will be adopted by a potential audience (p. 3). Achieving this multi-faceted creativity, which can lead to effective design ability, requires careful planning and orchestration on the part of the classroom teacher, a point that leads directly into the third challenge identified here.

The Challenge of Harnessing Design Activity to Enhance Learning. Cropley (1997) cited a number of resources dating as far back as the early 1970s that were developed to teach creativity. These resources ranged from activities or games, to packages of materials designed for regular use as an established curriculum. Cropley referred to these strategies as "the *technology* of creativity training," because they serve as tools that can be used for creativity "workouts," much like gym equipment is used for physical workouts (pp. 84-85). In spite of the availability of such materials, Cropley noted that "there is only limited evidence that such approaches actually increase creativity" (p. 85), particularly in new settings. Here, Cropley distinguishes the more limited view of creativity, as ability to generate ideas, from what might be called a more *productive* creativity:

> The sudden inspiration view is explicitly rejected [here] . . . on the grounds that it does not provide a basis for systematic, purposeful broadening of students' intellectual activity . . . . The important point for educators is that, apart from sheer chance—which cannot be harnessed by any classroom procedures because its essence is that it is blind and random—even accidental creativity requires a strong base involving activity in a field, a rich stock of information, and possession of appropriate attitudes, values, skills, and the like. Promotion of all of these lies within the teacher's province. (Cropley, 1997, p. 91)

PREPARING TEACHERS TO PROMOTE CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

What are the characteristics of teaching practice that promote development of design abilities in students? Craft (2006) cited over a dozen studies that suggested teachers who promote creativity and design successfully employ many of the following strategies:

- Developing children's motivation to be creative. This motivation can result, in part, from selecting tasks that students enjoy and are interested in.
- Fostering in-depth knowledge of a subject, to enable students' capacity to go beyond their own immediate experiences and observations.
- Using language to stimulate and to assess creative work.
- Offering a clear curriculum and time structure to students for creative activity, but involving them in establishing new routines when appropriate.
- Providing an environment where students can go beyond what is expected and rewarding them for doing so.
- Helping students find personal relevance in learning activities.

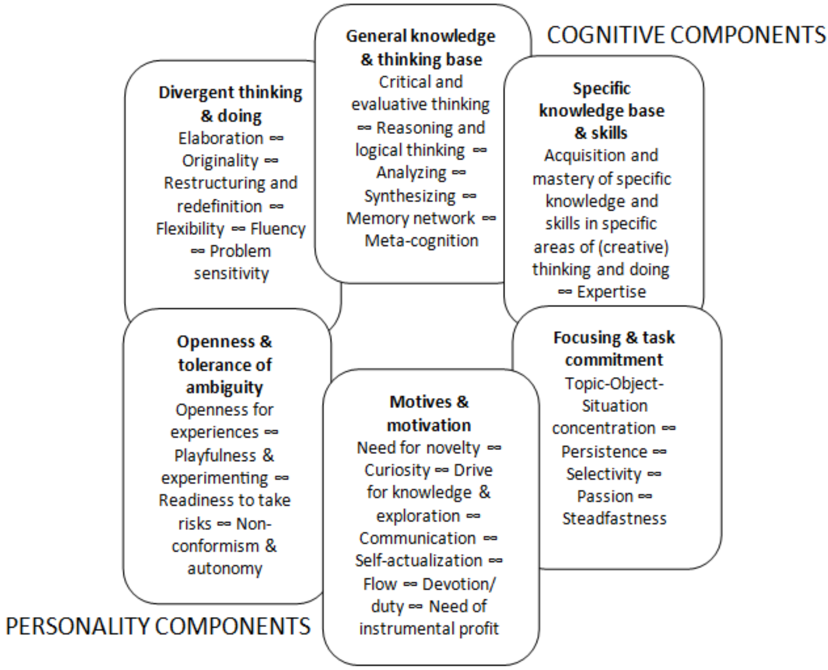
- Helping students learn about and understand existing conventions, while also modeling the existence of alternative approaches.
- Encouraging students to explore alternative ways of acting and doing, and being supportive of differences.
- Giving children enough time to incubate their ideas (Craft, 2006).

Necessary Understandings and Skills for Design Thinking Among Students. Descriptions of the types of understandings and skills needed for effective design thinking are plentiful, and a detailed treatment of these types is beyond the scope of this chapter. Readers are referred to other chapters of this Yearbook for more in-depth examinations of the characteristics of creativity in individuals.

Nevertheless, the topic warrants some attention here, because to structure teaching to promote creativity and design, one must have a sense of what the desired characteristics entail. Specific skills include the ability to engage in problem finding (Jay & Perkins, 1997); "making skills," the lack of which has been noted by Barlex (2007) as being a primary factor in students' inability to tackle design problems (p. 152); the capacity to engage in self-assessment, including ability to substantiate claims and ideas (von Oech, 1983; Jackson & Sinclair, 2006); and communication skills. A general consensus is that for creativity to be productive it must be demonstrated to have relevance and effectiveness in a broader context, and thus must be effectively communicated to others. If an idea "lies hidden within the individual it cannot be validated by the society" (Cropley, 1997, p. 89), a necessary prerequisite for gaining value from creativity. Dym, et al. (2005) discuss the various "languages" that are used in engineering design. These languages include verbal and textual, graphical representations, and mathematical models. Sketching plays an important role in the design process by helping designers work out ideas, providing documentation of ideas, and as a means of communicating ideas to others.

A holistic conceptualization of the components of creativity has been developed by Urban (2007) in his "componential model of creativity" (pp. 170-175). The model is divided into two "classes" of components, three of which are "cognitive components" and three of which are "personality components." At the risk of oversimplifying Urban's model, his six components of creativity are identified in Figure 1 (next page). Taken together, the components of the model represent a comprehensive listing of the traits generally found in the literature as being associated with creative activity. Urban poses the componential model as a "functional system," in which "each (sub)component plays its interdependent, functionally adequate role at a certain stage, a certain level, a certain situation" (p. 174), and in which no single component is sufficient on its own to lead to a creative product.

Figure 1. Elements of Urban's Components Model of Creativity



Note. Adapted from "Assessing Creativity: A Componential Model" by K. K. Urban (2007) in A. Tan (Ed.), *Creativity: A Handbook for Teachers*, p. 171. Copyright by World Scientific.

Instructional Strategies for Promoting Creativity and Design in Students. Instructional strategies are the methods and techniques teachers use to facilitate student learning (Oliva, 2001). In any given context, teachers have to make decisions about which strategies will best serve the learners, the material, and the desired learning outcomes. Most teachers are familiar with common approaches such as lecture, group activities, and laboratory work, but some strategies are particularly important to consider when development of creativity and design abilities is the goal.

Use of questioning. Roger von Oech, in his widely-used book *A Whack on the Side of the Head* (1983), offered a series of tips for creative problem solving that were written in a humorous and accessible way. These tips mirrored the strategies that have emerged in the research from education, psychology, and organizational leadership focused on creativity. Von Oech's writing style and the quirky illustrations found in the book enhanced its appeal for the lay reader, and some technology educators have found it to be a useful text for use in design courses within their programs. The *Whack* book has been published in an updated 25th anniversary form, and von Oech also maintains a blog and web site (http://blog.creativethink.com/). The use of questioning is among the many strategies offered in von Oech's book.

One of the basic questioning techniques for teachers described by Sternberg and Williams (1996) is to question the assumptions made by students and others. As von Oech (1983) noted, "the answers you get depend on the questions you ask. Play with wording to get different answers" (p. 26). Sternberg and Williams (1996) advised that teachers should

> make questioning a part of the daily classroom exchange . . . . We all tend to make a pedagogical mistake by emphasizing the answering and not the asking of questions. The good student is perceived as the one who rapidly furnishes the right answers. (pp. 12-13)

However, in a design context students should be taught to rely less on rote learning and more on thinking through a problem. In promoting creativity and design, one of the most powerful questions a teacher or student can ask is "What if . . . ?"

There are two types of questions that are frequently employed in design: Divergent questions, which can be used to help generate ideas; and convergent questions, which can be used to help focus ideas. Dym, et al. (2005), offered another way of viewing the role of these two types of questions:

> The key distinction between the two classes is that convergent questions operate in the knowledge domain, whereas divergent questions operate in the concept domain. This has strong implications for teaching conceptual design thinking since, as the recently proposed concept-knowledge theory also argues, concepts need not have truth value, whereas knowledge does. Design thinking is thus seen as a series of continuous

> transformations from the concept domain to the knowledge domain. (Dym et al., 2005, p. 105)

In other words, questioning plays a key role in helping students validate their ideas, the process of turning the merely novel design into the relevant and useful design.

Landau (2007) differentiated the levels of questions used in the classroom to an even finer degree. In what she called the "spiral of creative questioning," Landau identified and described six levels of questions through which teachers "stimulate children to take action, first on an intellectual level, which becomes motivation, and then on a practical level. By asking questions, [students] . . . get closer to the essence of the problem and its consequences" (p. 190). The first level of questions are *descriptive*, focused on the present, and characterized as "Who, what, when, where, how?" types of questions. The second level of questions are *causal,* and focus on "Why?" questions. These causal questions lead to what Landau called *subjective* questions that link the situation to the student's emotions and curiosity. Examples of these questions include "How do I feel about it? What have I seen or experienced that is like this?" In the fourth level, questions focus on the *imagination* and include the important "What if . . . ?" question. *Judgment* questions represent the fifth level, and include questions like "Which is better or more important?" If judgmental questions are asked too soon in the creative thinking process, they may interrupt the flow of imagining alternative solutions. Finally, after solutions are identified, *future*-oriented questions can be used to encourage students to think beyond the immediate situation by asking questions such as "What else can I do? What else interests me?" (Landau, 2007, pp. 188-191).

Role modeling. For effective design education, teachers should serve as role models (Jackson & Sinclair, 2006). This adage means demonstrating through one's style and one's actions both the mind-set and the tasks that are associated with the design process. For example, teachers can be open to multiple solutions to design challenges (adopting a *problem-based approach),* rather than insisting that every student create a similar product (adopting a *project-based approach).* Teachers can make frequent use of analytical and open-ended questions. They can facilitate student success by providing necessary tools and materials and by offering skill-building instruction as needed. They can allow for student collaboration on projects, and can adapt their assessment strategies to accommodate multiple types of solutions. "You cannot follow a recipe for developing creativity—first, because there is none; second, because such a recipe would provide *uncreative* role-modeling. Instead . . . show students your creative process to encourage them in their own creative thinking" (Sternberg & Williams, 1996, p. 8).

Being a guide. Torrance (1962), in his seminal work *Guiding Creative Talent*, detailed the role of the teacher in the relationship between teachers and creative students. Noting the susceptibility of teachers to adopt "the strategy of omnipotence and omniscience" (p. 170), he suggested the alternative of "*being* a helpful guide" who offers knowledge and expertise to students in pursuit of their own ideas or hypotheses. This last point is critical, because the locus of control for initiating ideas and making decisions must come from the student, not from the teacher, for true creative development. The teacher serving as guide can "express opinions, make judgments, [and] give information," but the student should be the one "to initiate, to propose, even to test" ideas (p. 172). This type of relationship does not deny the teacher his or her role of authority in the classroom, but it does acknowledge the role of the students as active agents in their own learning. Another way of describing this relationship has been posed by Craft (2006), who described "creative learning" as a kind of apprenticeship in the classroom, where the teacher (or "expert adult") provides induction to the apprentice (or "novice"). Included in this approach is the importance of the locus of control resting in the hands of the student (p. 23); just like in a traditional apprenticeship, the goal is to help learners develop into successful and independent practitioners.

Allowing collaboration. The essentially collaborative and socially-situated nature of creative design work is widely acknowledged. There is, first, the recognition that productive creativity involves development of ideas and products that are of value to a larger audience (Cropley, 1997). This collaboration represents a kind of peer review, through which "gatekeepers" accept or reject a creative product, thus allowing it to enter the shared body of knowledge or ideas (Sawyer, 2003). Second, and more germane to the classroom setting, is the recognition that in practice creativity is often manifested through collaborative interactions or improvisations with others (Sawyer, 2003; Dym et al, 2005). In many situations, "it is the entire system that creates, not the individual alone" (Sawyer, 2003, p. 19). Collaborators in a classroom setting provide, if nothing else, a forum for proposing ideas (Sternberg, 2003). At their best, collaborations can provide transformative interactions among participants (Moran & John-Steiner, 2003).

Examples of collaborative activity might be said to fall along a continuum, with strategies such as group brainstorming falling at the lower end and “long-term engagement, voluntary connection, trust, negotiation, and jointly chosen projects” characterizing the higher end (Moran & John-Steiner, 2003, p. 82). Given the constraints of the classroom, long-term collaborations among students might not be realistic. However, to the extent that meaningful collaboration is possible it should be fostered and accommodated within assignment guidelines and assessment strategies.

Establishing a creative environment. Environmental characteristics of the classroom can include physical features such as layout of space, availability of tools and equipment, and availability of work areas for individuals and for groups. They can also include cultural features such as openness to new ideas and ways of working, structuring for collaboration, and teacher-student interaction styles. The classroom teacher plays a dominant role in establishing classroom procedures, and these play a role in encouraging—or discouraging—creativity in design. Classroom procedures can become what Styhre and Sundgren (2005) called “stabilizers,” or the “established fixed repertoires of behaviour programmes [sic] over time” that can become overly rigid (p. 173). Destabilizers, or what von Oech called “perturbations” (1983, p. 52), may be necessary to challenge conventional thinking and to promote creativity, particularly when routines have become stifling. Classroom destablizers might include changing work groups, changing work routines, taking instruction out of the classroom, and so on. However, care should be taken not to overdo it: There is a difference between shaking up routines and chaos.

Most writers stress the need for providing adequate time for creative thinking, whether it is in the classroom or in the workplace. “By building in time for pondering, you show students that time spent thinking is valuable. Creative ideas depend on nurturing the inklings that lead to these ideas, and nurturing creative ideas requires time” (Sternberg & Williams, 1996, p. 21). In their work with primary school teachers, the developers of the UK Nuffield Project discovered that an “immersion experience” in design activity of several consecutive days in a term provided “a much more robust and meaningful experience for young children than the equivalent amount of time ‘drip fed’ over many weeks as one or two single or double lessons per week” (p. 153), an observation echoed by Stein, Ginns, and McDonald (2007).

One aspect of allowing adequate time for design thinking is the need to delay making judgments about student ideas until they are clearly formulated (Cropley, 1997). This time delay goes both ways: It relates to the timing of teacher assessments of student work, as well as to the students' self-evaluations of their own work. The latter runs counter to the documented tendency of many students to latch onto their first ideas (Jeffery, 1991; Mawson, 2007; McLellan & Nicholl, 2009). Additional time may not be sufficient to counteract the tendency of students to fixate on their first ideas; however, teachers will also likely need to provide specific instructions about how to think through design challenges more comprehensively, using interventions that encourage students to look beyond first solutions (McLellan & Nicholl, 2009).

Although it may seem self-evident, teachers need to also offer students opportunities to work with a wide variety of materials and tools, and to experience design thinking in different contexts. In other words, creativity is likely to flourish more readily in classroom environments that are rich with resources to both inform and stimulate thinking (Doyle, 1991).

Use of design and problem-solving models. So-called design or problem-solving models are ubiquitous in the literature on the subject, and the variations are too numerous to cite here. These models have a role in the technology education classroom, particularly for teachers who are new to using a design approach, because they help identify key stages of the design process and can "bring order" to otherwise messy conditions:

> A schematic of train routes in a city reduces journeys to their basic elements by factoring out the twists and turns of the route in actuality. Conceptual representations of journeys are more pleasing and practical to commuters than empirical ones. The purpose of design models in the classroom is not to deny the messiness along the way but to help students monitor critical points in the design journey. (Lewis, 2008, p. 258)

Indeed, when models of design activity are used for their conceptual value in illustrating the various phases of design work they serve a useful function. However, too often teachers focus on *knowing the model* as the goal of learning, rather than on the underlying abilities and insights they represent. Requiring that students demonstrate a lock-step adherence to a model represents a superficial approach to engaging them in design activity. Furthermore, instructional models that expect students to follow an established progression through predetermined steps are at odds with the approaches that students naturally take in the development of ideas. In particular, requiring that students generate a given number of ideas before settling on a design solution "may be actively discouraging students from developing their design ideas by the route of prototype modification. It is not so much how many different ideas there are that matters, but what is done with one of them" (Jeffery, 1991, p. 150). Similarly, Lewis (2008) noted that formulaic approaches are often subverted by students and that such approaches can, in fact, stifle student creativity.

Assessment. An aspect of assessment that is sometimes overlooked actually represents a necessary *precursor* to assessment: Students need to be provided with clear expectations. For example, in their study on fixation, McLellan and Nicholl (2009) found that teachers frequently used product analysis as a preparatory activity in their design classes, but typically students were not given instructions on how to approach this task, nor on what to do with the information they collected. This problem speaks to the importance of two other teaching strategies, modeling and scaffolding. Although it may seem counter-intuitive when discussing open-ended design activity, it is imperative for teachers to clearly identify what it is they expect from students via written instructions and "examples that reinforce spoken instructions" (Jackson & Sinclair, 2006, p. 129). If a teacher is dissatisfied with the quality of students' work, his or her first task is to examine the quality of the instruction provided.

Students also need to be provided with timely and ongoing feedback regarding their design activities. A majority of this feedback will be informal/formative and can focus on guiding students through tasks, questioning them regarding their design thinking, or providing feedback on ideas. Although focused on creativity in organizational settings, Whatmore (1999) offered an interesting perspective on the tone of feedback provided by mentors:

> If feedback is focused on *failure*, then people become more averse to risk and more concerned to ensure that their reputations are about success and achievement [rather] than about risk and creativity; where feedback is more about *effort*, people are less interested in problems and 'process' and more interested in showing how busy they are. Where feedback is *not available* at all, people feel dismissed. (p. 161)

Finally, the issue of summative assessment must be addressed. In an age of standards and mandatory testing, the problem noted by Torrance

(1962) of overreliance on convergent, cognitive assessment strategies is little changed today, and may in fact be exacerbated. Educational programs are largely set up to reward recall of factual information and use of standardized processes and techniques. Thus, when faced with the need to evaluate creative design activity, teachers experience what Cropley and Cropley (2007) labeled "the grading problem" (p. 214):

> The heart of the matter is specific, concrete information and objective correctness/incorrectness. Creativity, on the other hand, emphasizes novelty, ambiguity, uncertainty, and the like. Not only do teachers and students dislike this, but also it raises the risk of *disagreement over the value of answers* (if they are not correct/incorrect, how is one better than another?), *subjectiveness* (are differences in answers dependent more upon the knowledge, beliefs and values of a particular assessor than on some objective criteria?), and *arbitrariness* (are grades affected by whims, changing moods, short-term fads, etc?). (Cropley & Cropley, 2007, p. 215)

In response to this problem, it is possible for teachers to incorporate into their assessment strategies tools that enable them to evaluate more open-ended work such as design products. These assessment tools can take the form of checklists or rubrics that operationally define the desired characteristics sought. One approach is offered by Cropley and Cropley (2007), who prepared a list of guidelines for assessing creativity. It included principles, criteria, and—most helpfully—indicators that serve to define observable elements of creativity. An abbreviated version of their model is provided in Table 1 (next page). Obviously, different indicators can be identified when other, specific types of outcomes are desired (e.g., if one wanted to emphasize various characteristics of design activity).

Cropley and Cropley (2007) have investigated use of this scale with teachers, where the list of indicators served as a checklist for assessing student work and students got a score of one if an indicator was present or a zero if absent. After very minimal training in the use of the instrument teacher scores were consistent with those of expert raters. Also notable was that students' level of acceptance for the instrument was high (pp. 222-228).

Table 1. Creativity Assessment Scale

Criterion	Indicator
Satisfying requirements in the problem statement	• *Correctness* (solution reflects conventional knowledge and techniques) • *Effectiveness* (solution does what it is supposed to do) • *Appropriateness* (solution fits within task constraints)
Problematization	• *Diagnosis* (solution draws attention to shortcomings in what already exists) • *Prescription* (solution indicates how what already exists could be improved) • *Prognosis* (solution indicates likely effects of changes)
Addition to existing knowledge	• *Replication* (the known is transferred to a new setting) • *Redefinition* (the known is seen or used in a new way) • *Combination* (generation of new mixtures of existing elements)
Developing new knowledge	• *Redirection* (the known is extended in a new direction) • *Generation* (construction of fundamentally new—but at least potentially effective—solutions)
External elegance	• *Convincingness* (the beholder is convinced by the solution) • *Pleasingness* (the beholder finds the solution attractive)
Internal elegance	• *Completeness* (the solution is well-worked out and not fragmentary) • *Harmoniousness* (elements of the solution fit together in an internally consistent way)
Ideas are "generalizable," or go beyond the immediate problem	• *Foundationality* (solution lays down a general basis for further work) • *Transferability* (solution offers ideas for other, apparently unrelated problems) • *Germinality* (solution suggests new ways of looking at existing issues or problems) • *Seminality* (solution draws attention to previously unnoticed problems)

Note. Adapted from "Using Assessment to Foster Creativity" by A. Cropley and D. Cropley (2007).

CURRICULAR PLANNING FOR DESIGN ACTIVITY IN TECHNOLOGY AND ENGINEERING EDUCATION PROGRAMS

A host of curriculum resources is available to the technology teacher who wants to incorporate a design approach to teaching and learning. Some states (e.g., North Carolina) have established programs of study for technology education that include design content. Even where there is a required curriculum model in place, teachers generally need to draw on outside materials, which abound. No matter what curriculum materials are drawn upon, the same requirements apply: They should provide meaningful opportunities for engagement (i.e., represent authentic or "rich" tasks); they should provide age-appropriate opportunities for development of intellectual and design skills; and they should be feasible for a given classroom's resources. Most importantly, the materials and activities selected should be ones that provide contexts and opportunities for enhancing student technological literacy, as they learn more about technological concepts through the process of designing.

Design standards in Standards for Technological Literacy. As any reader of *Standards for Technological Literacy* knows, design is a central component of these standards. The document provides a fundamental argument for inclusion of design as a focus within technology education:

> Design is regarded by many as the core problem-solving process of technological development . . . . Because technological design involves practical, real-world problem-solving methods, it teaches valuable abilities that can be applied to everyday life and provides tools essential for living in a technological environment. (International Technology Education Association [ITEA], 2000, p. 90)

More than just a static list of standards, this document does provide valuable insights into the nature of design and technology, as well as about the essential understandings that need to be cultivated in students. For example, Chapter 5 outlines the attributes of design, the types of tasks undertaken by designers, and the considerations of designers in technological contexts. Standard 11 outlines some of the skills students will need to engage in design work. Short vignettes also help to illustrate design in classroom settings. The inclusion of design so prominently in this document illustrates its ascendancy as a recommended instructional strategy, and also makes the document useful reading (or re-reading) for classroom teachers.

More recently, the ITEA (now ITEEA) has developed a set of curriculum materials, called *Engineering byDesign* (EbD), that are based on the standards. These materials are currently available to teachers in states that are part of ITEEA's Consortium of States, which as of this writing, includes 20 states. Of the many curriculum models available across the United States, these materials arguably track most closely to *Standards for Technological Literacy.* However, a number of instructional materials can be found that address design, or "engineering design," in some fashion. Among the most well-known are *Project Lead the Way* (PLTW) (www.pltw.org) for middle and high school, Georgia Tech's *Learning by Design* program (http://www.cc.gatech.edu/projects/lbd/htmlpubs/SMILE.html) for middle school, and *City Technology: Stuff that Works* (www.citytechnology.org) for elementary school. Many of the materials are proprietary (e.g., PLTW and EbD), while others can be accessed free or for a minimal cost.

In any case, it is unlikely that access to these documents alone will be sufficient for instilling the understanding and instructional skills needed for the most effective teaching in a design and technology classroom. These materials, like any curriculum document, can provide a launching point, but most teachers will find it necessary to engage in ongoing professional development related to various aspects of teaching design, including collaborative interaction with fellow teachers (Mawson, 2007; Stein, Ginns, & McDonald, 2007; Williams, 2008).

Translating Curricula into Classroom Practice. Jones and Compton (1998), in their report of research on teacher adoption of a new technology education curriculum in New Zealand, highlight an important consideration when asking teachers to change their teaching practice or to adopt new approaches. In their view, "teachers will need to experience technological praxis and technics in some form to become confident in the teaching of technology. Learning about technological practice is not sufficient" (p. 63). Citing the work of Donald Schön, they noted that teachers must be able to recognize design qualities and to understand the process of design holistically, abilities that are learned by doing. Their advice is critical to understanding how we can best prepare teachers who are confident and comfortable with leading design-oriented instruction. On the other hand, Mawson (2007) found, when studying the experiences of design practitioners who were completing teaching practicums, that these designers/student teachers were not necessarily able to make the transition from successful design work to successful design teaching:

> There was a clear difference between the success these students had in their own design task in the college of education, and the lack of success they had in scaffolding the design process with their secondary school students on practicum. Personal knowledge and understanding of the design process . . . did not automatically enable them to effectively support the development of the design practice of students in secondary school settings. (p. 173)

This conclusion suggested that two different strands of knowledge and experience are critical for effective design-oriented instruction: The teacher must have a holistic understanding and experience with the processes of design, but must also have an understanding of pedagogical strategies such as scaffolding and differentiation, as well as of the existing capabilities of the students.[1]

EXAMPLES OF PROFESSIONAL DEVELOPMENT IN DESIGN AND TECHNOLOGY AND ENGINEERING EDUCATION

Important work can be done at both the pre-service and in-service levels to prepare design and technology teachers. The examples that follow help to illustrate how some of the characteristics of design education described throughout this paper can look in practice.

In-service Teacher Education: The Nuffield Project. The United Kingdom-based Nuffield Project comprises the Nuffield Secondary Design and Technology Project (http://www.secondarydandt.org/) and the Primary Design and Technology Project (http://www.primarydandt.org/). The Nuffield Design & Technology Project was established in 1990 as a mechanism for supporting teachers and learning in design and technology and, more specifically, for supporting this content area in the UK National Curriculum. Teacher support through this long-standing project (the Secondary D&T Project was discontinued in 2008) was accomplished, in part, via distribution of resources and through professional development workshops. As described by David Barlex (2007), the Director of Nuffield Design and Technology, the pedagogy developed through the project contained three types of learning activities. These activities included

> Resource Tasks, short often practical activities that [teach] specific skills, knowledge and understanding likely to be useful in tackling a

> designing and making activity; Capability Tasks, longer more open designing and making activities; and Case Studies, true stories about design & technology in the world outside school to enable pupils to put their studies into a wider context. Through a careful combination of these types of learning activity across a number of years a teacher could construct a learning experience that was broad, balanced, covered the required programme of study and met the requirements of continuity and progression. (Barlex, 2007, p. 152)

Barlex stressed that he and his colleagues' approach to development of resources was to listen carefully to teachers to better understand their views and needs, recognizing that these needs had to be taken into account for successful implementation. They included instructional needs of teachers, including print or online curriculum resources, as well as physical resources like tools, equipment, and consumable materials. In addition, they included the needs of the classroom setting (e.g., determining the most effective ways to engage students in design activity). Two other important requirements cited by Barlex included teacher expertise and support within the teaching community, or what might be described as the presence of a culture in which design education is recognized and valued. The importance of a supportive educational culture is a need also identified by Mawson (2007).

The materials developed through the Nuffield Project are readily accessible on the Projects' web sites. Although specific to the UK National Curriculum, these materials are well-developed and informative. In addition to curriculum materials, the site contains research reports, teacher stories, samples of student work, and links to other useful sites.

One of the issues brought up repeatedly by Barlex (2007) is the need for research on the efficacy of various instructional strategies in the design/technology classroom. This recommendation is an area where teachers can make a tremendous contribution. Technology teacher educators should promote action research among teachers and perhaps enable action research by collaborating with classroom teachers.

Pre-service Teacher Education: Case Study of John Belt, SUNY-Oswego. The Department of Technology at the State University of New York (SUNY) at Oswego offers two tracks, one in technology education and another in technology management. All majors within the department are required to enroll in Professor John Belt's *Design and*

Technology course, a three-semester-hour offering that introduces students to aspects of the design process and provides them an opportunity to apply that process in completion of what John calls "authentic design problems." Students can build upon their experience in the *Design and Technology* course by choosing to do additional work with Professor Belt, including his senior-level elective course called *Design Probe*. An examination of John's design philosophy and of his instructional approach provides a view of how one university has effectively integrated design into its programs, including technology teacher education.

A fundamental premise of the approach taken by John Belt and his colleagues is that design is something that must be experienced to be understood: It's not possible to *teach about* design without having students *engaged in* design. To put it in John's words: "I can't teach one to be a designer; I can teach one what design involves." He sees his role as providing an environment in which students can take charge of their learning by identifying meaningful design problems and solving those problems using the design skills and understandings they have developed along the way.

Another important aspect of the SUNY-Oswego approach is that design is embedded throughout the program curriculum; it is not just addressed in one or two courses and then set aside. Within even a brief discussion with John about his *Design and Technology* course you are likely to hear what may be his mantra: "Design is a verb, not a noun." In other words, what design is *about*—its power and potential—is the actions of conceptualizing, creating, analyzing, and communicating, which result in appropriate solutions to identified problems and needs. It is this process that teachers must help their students to understand and to apply, because it is this process (and the whole subset of skills that it entails) that will empower those students to achieve in any number of contexts both inside and outside of the educational environment.

In the *Design and Technology* course, John uses strategies to help his students understand design and the nature of design. For example, they spend time discussing design elements and principles. John asks each student to bring in a different book that lists and defines the "design elements" and "design principles" that relate to visual design. In John's experience, descriptions and inclusion of terms can vary widely, depending on the source. Class members then assemble a list of all the items they have found that are identified as an element or principle of design. Once students have a preliminary sense of the visual language used to discuss artifacts, they then study structural and physical principles. By examining a variety of conceptualizations, the students can identify patterns that emerge and can begin to build an overarching understanding of the terms. Principles include more abstract qualities like contrast, rhythm, scale, proportion, and balance. Elements are those things that you can touch or put your finger on, such as color, shape, and texture. In John's view, design principles serve as guides or strategies for manipulating design elements. For example, *contrast* is a visual concept (a principle) that can be brought forth through use of *color* (an element). What John hopes will result from these class discussions and from the experience of seeing how these principles and elements are applied in practice is that the terms become part of the "design language" that students can employ when they analyze their own or others' design solutions. Moreover, the design principles and elements that relate to one area of design (e.g., visual design) have corollaries in other areas of design, such as functional and structural. An exercise that John incorporates into his class involves students in observing designed artifacts around them. This strategy enables students to better see and understand design principles and elements as manifested in artifacts, and to in turn apply them in their own work "in some kind of meaningful way." This type of observational exercise also helps students to understand more about design in context (i.e., what makes particular design solutions better for the settings and spaces in which they will be used). In John's view, all artifacts can be probed or designed by carefully analyzing the visual, functional, and structural design needs that had/have to be addressed. Good design solutions effectively meet *all* of the visual, functional, and structural needs as well as endure for their intended life spans.

John also tries to build in his students a holistic understanding of the design process. Once again, he asks students to find examples of design processes that are described in books. Based on these various examples, the group builds a list of all of the versions that are uncovered, which can range from common four-step design processes used with young children to more complex processes with nine or more steps. John's students again look for patterns and identify the major design "phases" that are evident in all of the lists. He tries to help his students understand the phases of the design process conceptually rather than simply memorizing a list of "steps," which erroneously suggests that design is linear. From John's point of view, what is important is that designers are "sensitive to doing what needs to be done at a given place in the journey toward a meaningful solution." Instead of following a mental checklist, they should be able to understand and use the principles and elements of design as they think their way through a problem.

Another unit in Professor Belt's course focuses on writing design briefs. Early on in the course he engages them in designing based on challenges or problems that he has identified (with opportunities to select other problems), but by the latter part of the semester students will be expected to identify their own design challenges and to write briefs based on those challenges. The format he likes them to use for their open-ended design briefs includes four components. First is a statement of the problem to be solved, which should say nothing about possible solutions. Second is the design statement, or what John calls "the mission directive." This should not dictate what the outcome will be, simply what the *intent* is, and it should allow for many possible solutions. The third component is an identification of the "artifact constraints" that apply. In other words, what are the parameters or guidelines that help to define and focus the project? These parameters could include budget, time, style, material, and other issues as established by the "client" or designer in charge. Fourth, John asks his students to identify educational constraints, or what he alternatively calls "priority educational experiences" that describe the knowledge, skills, or abilities the students need or want to experience or develop through the process of designing a solution. This component essentially asks students to think about their larger goals in pursuing a particular design challenge and how they will use that opportunity to expand their capabilities.

The relatively open-ended approach that John uses with his undergraduate students may not be feasible to use with middle or high school students: It may simply not be possible to allow students the leeway to generate their own challenges. Although high school students would benefit from selecting their own problems, this endeavor will place more demand on teachers to guide the direction and progress of the design activity. As John noted

> Most teacher-written design briefs that I find are basically assignments; they often do not have a problem statement at all and the student simply has to produce a given solution. Sometimes it's okay to have a directed outcome like this, because you can teach certain things or focus on specific issues such as sketching,

modeling, or learning to work within given constraints. (John Belt, personal communication, July 10, 2010)

For inspiration in identifying design challenges and for thinking through the solutions to those challenges, John draws upon a host of resources that he shares with his students and may sometimes use as required readings. One of his required readings in recent years is the book *Cradle to Cradle* by William McDonough and Michael Braungart, published in 2002. An early (and enduring) inspiration for John was Buckminster Fuller, whose visionary work with materials, structures, and systems provided a whole new way of looking at the designed world and its place in nature, as well as about the responsibility of the designer to consider the needs of the end users and of the environment. John, like others, sees nature as a profound source of insight and ideas for new ways of designing. He also cites the work of architect Frank Lloyd Wright; biologist John Todd; designers George Nelson, Charles and Ray Eames, and Ralph Caplan; and educator Sidney J. Parnes, co-founder of the International Center for Studies in Creativity at the University of Buffalo, as influences. A somewhat quirky and dated but still very useful resource that John has also used is the book *The Universal Traveler* by Don Koberg and Jim Bagnall, first published in the early 1970s and still available today via book vendors such as Amazon.

When asked how he would structure a professional development workshop for technology education teachers, John said that it would be a variation on the *Design and Technology* course he teaches to undergraduates. It would include a focus on the professional language or “jargon” of design (e.g., the principles and elements), which provides a common ground so that other people can “see what you see when you are talking.” It would also include a focus on identifying and developing activities that are appropriate for students at varying stages of their design development, from novice to experienced designer. This recommendation acknowledges that students are capable of different types of tasks at different levels of design experience. For example, early design challenges can be more structured projects that allow students to develop their technical skills by studying the design work of others. They would move onto more open-ended tasks that allow for the development of more sophisticated design skills, such as modeling and prototyping. By carefully selecting the exercises John gives his students, he can progressively build their design skills. Thus, the approach might be thought of as moving from a project-based, skill-building approach to an open-ended, problem-based approach, which is the ultimate goal of a design orientation.

Finally, John says it is important for teachers to develop their awareness of how to find problems. They can locate problems by continually scanning their surroundings, looking at products and processes, and searching for areas in need of improvement. All designers engage in this activity; teachers can take it a step further and think about how they could turn everyday problems into fruitful classroom design exercises.

John takes some issue with the recent emphasis on engineering design; in his view, “it’s all design” and adding the word *engineering* to infer a better or different kind of design is not always helpful and does not square with design practice. Regardless of the particular design process model that one examines, students will be engaged in similar phases of design. In the end, John notes, we need to remember that it is “design *as* process, not *the* design process.” Thus, we should think more about helping students understand and practice the actions of designers (design as a verb) and focus less on the static designed artifact (design as noun).

In a follow-up interview with two of John Belt’s former technology education students, I was able to gain some insights into the outcome of his style of teaching about design. One comment they made, in particular, was telling. They reflected on typical activities such as building a CO2 car or a glider: “If you have students use kits to make gliders and they all look the same and they all work, that’s the lowest level of technology education.” On the other hand, “if you have twenty different gliders and some work and some don’t, but you’re really studying what makes them fly, that’s good technology education.” They noted about Professor Belt that “John *wants* you to have a product that doesn’t work, so you learn from it.”

In these students’ opinion, the goal of John’s design instruction was for students to experience a “holistic approach to working your way through a problem.” They said that in every class he threw them “a curveball, something unexpected but totally planned on his part” to get them thinking or experiencing things in a different way. For example, in one class he lectured students in the dark, and toward the end of class started talking about lighting design. In these students’ view, the most critical element in design is asking the question “why?”—*why* are you making it that shape or that color?—and “if you could change that one thing about the way people teach technology education, it would make a difference."

CREATIVITY AND DESIGN RESOURCES FOR TEACHERS

Sternberg and Williams (1996) suggested the use of stories of creative individuals and their work to help students better understand the creative process. The stories should include "information about (1) the problems and related concepts, (2) the procedures used to solve the problem, and (3) how the components of the case are related" (p. 38). This approach will elicit "case-based reasoning" about the creative process. There are many sources of inspiration and ingenuity that can serve as the foundation for classroom stories. Information about three such resources that may provide springboards for classroom discussions and activities follows.

Cooper-Hewitt National Design Museum. One of the most accessible sources of information on design education activities and resources for students and teachers is the Cooper-Hewitt National Design Museum web site (www.cooperhewitt.org). The Cooper-Hewitt, a branch of the Smithsonian Institution since the mid-1960s, is located in New York City. It was established in 1897 by the Hewitt sisters, granddaughters of industrialist Peter Cooper, as part of the Cooper Union for the Advancement of Science and Art. The Museum has a primary focus on historical and contemporary design, and within that focus maintains a multifaceted plan of work that includes museum collections, a design library, and educational programs. Although there are on-site professional development programs for teachers, there is also a comprehensive set of resources available online. Several of these programs will be highlighted here.

The Educator Resource Center of the Cooper-Hewitt web site notes that "design makes any subject immediately relevant to students by directly relating to their real-life experience" ("Design in the Classroom," para. 1). This philosophy is supported by the broad nature of the educational resources available, ranging in emphasis from the artistic to the social to the technological. It is the latter set of activities that should most interest technology and engineering teachers. The site features an easy-to-browse database of lesson plans that can be searched by subject area and by grade level. For example, in 2010 a search of middle school activities using the subject areas of technology, math, and science yielded a total of 52 lesson plans and for the high school level, there were 80 lesson plans available online. Teachers should probably not limit themselves to these subject areas, however. A database search that also includes art, social studies, and language arts can yield significantly more lesson plans.

One featured lesson plan on the site is titled "Green Transportation System." This activity, developed at the Cooper-Hewitt, asks students to use the maps provided to discuss and design a public transit system to serve two areas. Like the other lesson plans in the database, this activity identifies national standards addressed by the activity (in this case, including two of the ITEA *Standards for Technological Literacy).* It provides useful links, background information, and step-by-step directions for the teacher, as well as downloadable maps and materials.

Teachers who make use of the lesson plans may need to be selective about identifying the elements that will be most useful to the level of students they teach and to their particular settings. For example, the "Green Transportation" lesson just described can actually be found in three grade categories (elementary, middle, and high school), with very little differentiation in the activity description from one level to the next. Its focus on New York City would not fit well with students in rural areas or from other states. Nevertheless, the activity does offer resources and ideas that could be adapted by the individual teacher. A number of the lesson plans have been developed and submitted by classroom teachers and, again, may need some modification for use in other classrooms. It is possible for any teacher to submit a lesson plan; the process for registering as a member is quick and easy, and provides teachers with immediate ability to upload lesson plans.

As with many "off the shelf" instructional materials, these perhaps best serve as starting points for individual classroom teachers to apply their own design skills toward development of a lesson or activity that is tailored to their own students. Not to be missed on the Cooper-Hewitt web site are the many interesting resources that can serve to spark creative ideas. In particular, look for the "National Design Triennial" pages that highlight innovative designs across a broad spectrum of human activity, including energy, mobility, community, materials, communication, and "simplicity." Technology teachers will not fail to find ideas that pique the interest of their students and that can serve as launching points for classroom design challenges.

International Journal of Technology and Design Education. The *International Journal of Technology and Design Education* (*IJTDE*) is a quarterly journal devoted to design education at the K-12 and collegiate level. Articles are available online at the journal's web site: http://springerlink.com/content/102912. With 21 volumes in print as of 2011, the *IJTDE* represents perhaps the single most significant source of research articles in existence for design and technology teachers. (Readers will note that many of the sources cited in this chapter were drawn from the Journal.) The *IJTDE* web site is readily searchable, and all articles can be opened in PDF format. Engagement with the professional literature through reading and reflection is a powerful professional development tool for teachers. Many of the manuscripts published in the *IJTDE* will, moreover, provide teachers with useful insights into design practice in classroom settings. An added bonus is the truly international flavor of the journal, which helps one understand the commonalities in design and technology education programs worldwide.

U.S. Patent and Trademark Office. The United States Patent and Trademark Office offers online resources for children as well as for teachers and parents (www.uspto.gov). These materials are largely focused on helping students learn more about the various forms of intellectual property and how they are protected, as well as on providing historical information that can be used to engage students in these topics. There are curriculum resources for elementary, middle, and high school classrooms, including lesson plans, supplementary information, and worksheets. The curriculum materials identify national learning standards associated with each lesson, including those from science, social studies, language arts, and the National Educational Technology Standards (but not from the *Standards for Technological Literacy*). Aside from the curriculum resources for teachers, the so-called materials "For Kids" are more likely to appeal to a relatively young audience. For example, the kids' Fun House features a link for the "Little Shop of Patent and Trademark Horrors," which highlights such inventions as a magician's guillotine. Nevertheless, there are helpful materials for use with students of all ages, particularly with regard to understanding intellectual property and with regard to strategies for promoting inventive thinking.

CONCLUSIONS

As Loucks-Horsley, Hewson, Love, and Stiles (1998) note, strategies for professional development can take many forms, and those that are most effective for helping teachers translate new knowledge into practice include workshops, coaching and mentoring, curriculum implementation and adaptation, study groups, and participation in professional networks. Classroom teachers who do not have access to desirable workshops or institutes can nonetheless map out an effective professional development plan that includes selection and implementation of new curriculum materials, preferably with the support of colleagues and/or supervisors; participation in study groups with colleagues who implement design-oriented approaches; and engagement with colleagues within professional networks, either online or via meetings and conferences.

Despite the greater emphasis on design knowledge and design activity in technology education content standards and curriculum documents, teachers in too many classrooms continue to focus superficially on having their students memorize and go through the "steps" of design or problem solving, failing to understand that these merely serve as representations of activity that requires careful planning, purposeful engagement, and new ways of structuring the classroom. To achieve a more comprehensive approach toward the inclusion of design activity in technology education, all of the participants involved in the field need to play a role. Teacher educators need to review the places and the ways that design activity is integrated into their programs, and then update the curriculum to address shortcomings. Teacher educators can also promote and engage in action research related to design in the classroom. Classroom teachers must seek out and pursue professional development activities, including the types of activities recommended by Loucks-Horsley, et al. (1998). Professional organizations can also play an important role by offering print resources for teachers and students, facilitating professional networks of design educators, and orchestrating professional development workshops and presentations at regional and national conferences.

REFLECTIVE QUESTIONS

1. Does your state provide curriculum resources for technology education? If so, do these resources promote design activity in the classroom? In what ways could these materials be improved?
2. In what ways does Professor John Belt's design program illustrate recommended characteristics of design education as reported in the literature of this chapter?
3. In which aspects of design-oriented instruction do you feel you need additional professional development? What are strategies you plan to pursue to acquire this professional development?
4. Consider a design problem that has worked well in your classroom, and that you feel has resulted in development of desired knowledge and skills among students. What indicators would you include on a rubric to assess student design work that has been produced in this activity?

AUTHOR NOTE

I am indebted to Professor John Belt of SUNY-Oswego for his generous commitment of time in discussing design education and for reviewing drafts of this material.

FOOTNOTE

[1]Definitions and elaborations on the teaching strategies of scaffolding and differentiation can be found at on-line sites such as the following: http://www.edutopia.org/blog/scaffolding-lessons-six-strategies-rebecca-alber.

REFERENCES

Barlex, D. (2007). Creativity in school design and technology in England: A discussion of influences. *International Journal of Design and Technology Education, 17*, 149-162. doi: 10.1007/s10798-006-0006-x

Craft, A. (2006). Creativity in schools. In N. Jackson, M. Oliver, M. Shaw, & J. Wisdom (Eds.), *Developing creativity in higher education: An imaginative curriculum* (pp. 19-28). London: Routledge.

Cropley, A. J. (1997). Fostering creativity in the classroom: General principles. In M. A. Runco (Ed.), *The creativity research handbook* (Vol. 1, pp. 83-114). Cresskill, NJ: Hampton Press.

Cropley, A., & Cropley, D. (2007). Using assessment to foster creativity. In A. Tan (Ed.), *Creativity: A handbook for teachers* (pp. 209-230). Singapore: World Scientific.

Doyle, M. (1991). *Physical facility factors for technological problem solving* (Unpublished doctoral dissertation). West Virginia University.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

Hostetler, I. (1960). What objectives should be emphasized in industrial arts? In M. L. Schmitt (Ed.), *Improving industrial arts teaching: A call to the profession* (pp. 11-22). Washington, DC: U.S. Department of Health, Education, and Welfare Office of Education.

Hutchinson, J., & Hutchinson, P. (1991, May/June). Process-based technology education. *The Technology Teacher, 50*(8), 3-6, 14.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology.* Reston, VA: Author.

Jackson, N., & Sinclair, C. (2006). Developing students' creativity: Searching for an appropriate pedagogy. In N. Jackson, M. Oliver, M. Shaw, & J. Wisdom (Eds.), *Developing creativity in higher education: An imaginative curriculum* (pp. 118-141). London: Routledge.

Jay, E. S., & Perkins, D. N. (1997). Problem finding: The search for mechanism. In M. A. Runco (Ed.), *The creativity research handbook* (Vol. 1, pp. 257-294). Cresskill, NJ: Hampton Press.

Jeffery, J. R. (1991, October). An investigation into the effect of systematic design methods in Craft, Design, and Technology (CDT). *International Journal of Technology and Design Education, 1*(3), 141-151. doi: 10.1007/BF00819647

Jones, A., & Compton, V. (1998, January). Towards a model for teacher development in technology education: From research to practice. *International Journal of Technology and Design Education, 8*(1), 51-65. doi: 10.1023/A:1008891628375

Landau, E. (2007). Educating toward the future: Asking questions. In A. Tan (Ed.), *Creativity: A handbook for teachers* (pp. 187-192). Singapore: World Scientific.

Lewis, T. (2008). Creativity in technology education: Providing children with glimpses of their inventive potential. *International Journal of Technology and Design Education*, *19*(3), 255-268. doi: 10.1007/s10798-008-9051-y

Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin Press.

Mawson, B. (2007). Designers and teachers and learners: Transferring workplace design practice into educational settings. *International Journal of Technology and Design Education*, *17*(2), 163-177. doi**:** 10.1007/s10798-006-0002-1

McDonough, W., & Braungart, M. (2002). *Cradle to cradle: Remaking the way we make things.* New York: North Point Press.

McLellan, R., & Nicholl, B. (2011). "If I was going to design a chair, the last thing I would look at is a chair": product analysis and the causes of fixation in students' design work 11-16 years. *International Journal of Technology and Design Education, 21*, 71-92. doi: 10.1007/s10798-009-9107-7

Moran, S., & John-Steiner, V. (2003). Creativity in the making: Vygotsky's contemporary contribution to the dialectic of development and creativity. In *Creativity and Development* (pp. 61-90). New York: Oxford University Press.

Oliva, P. F. (2001). *Developing the curriculum*. (5th ed.). New York: Longman.

Pedras, M. J., & Braukmann, J. R. (1990, March). Technology education—addressing new challenges. *The Technology Teacher*, *49*(6), 29-32.

Robinson, K., et al. (1999, May). *All our futures: Creativity, culture and education.* A report by the National Advisory Committee on Creative and Cultural Education. London. Retrieved from http://sirkenrobinson.com/skr/pdf/allourfutures.pdf

Rye, K. J. (1988, March). *Creative group problem solving in technology education.* Paper presented at the Annual Conference of the International Technology Education Association, Norfolk, VA.

Sawyer, R. K. (2003). Emergence in creativity and development. In *Creativity and Development* (pp. 12-60). New York: Oxford University Press.

Stein, S. J., Ginns, I. S., & McDonald, C. V. (2007). Teachers learning about technology and technology education: Insights from a professional development experience. *International Journal of Technology and Design Education, 17*(2), 179-195.

Sternberg, R. J. (2003). The development of creativity as a decision-making process. In *Creativity and Development* (pp. 91-138). New York: Oxford University Press.

Sternberg, R. J., & Williams, W. M. (1996). *How to develop student creativity.* Alexandria, VA: Association for Supervision and Curriculum Development.

Styhre, A., & Sundgren, M. (2005). *Managing creativity in organizations: Critique and practices.* New York: Palgrave Macmillan.

Torrance, E. P. (1962). *Guiding creative talent.* Englewood Cliffs, NJ: Prentice-Hall.

Urban, K. K. (2007). Assessing creativity: A componential model. In A. Tan (Ed.), *Creativity: A handbook for teachers* (pp. 167-184). Singapore: World Scientific Publishing.

von Oech, R. (1983). *A whack on the side of the head: How to unlock your mind for innovation.* New York: Warner Books.

Warner, S. A., & Morford, L. L. (2004, Spring). The status of design in technology teacher education in the United States. *Journal of Technology Education, 15*(2), 33-45.

Whatmore, J. (1999). *Releasing creativity: How leaders develop creative potential in their teams.* London, UK: Kogan Page.

Williams, P. J. (2008). Using DEPTH as a framework for the determination of teacher professional development. *International Journal of Technology and Design Education, 18*(3), 275-284.

Conceptual Framework and Perspectives for Creativity and Design in Technology and Engineering Education

Chapter

12

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Creativity has distinguished us as humans from the other species on Earth. This ability has provided technological progress and advanced civilization. It has enabled us to appreciate beauty, relieve some of our stresses, and enjoy life. During times of our creativity, we have reached some of our peaks in life and felt our deepest sense of satisfaction, fulfillment, and self-actualization.

Rapid change in our lives, our communities, and throughout the world has continually established the need for fresh ideas, new tools and techniques to adapt to our environment, and novel solutions to complex problems. Increasing levels of information, advancing technology, and international situations have expedited the need for critical and creative thinking for prosperity and at times survival (Sternberg, 2010).

Human creativity has been overwhelmingly called upon to meet educational, economic, and career needs for the twenty-first century (American Management Association, 2010; Cable, 2012; Florida, 2002; Friedman, 2011; Hennessey & Amabile, 2010; Koenig, 2011; Lichtenberg, Woock, & Wright, 2008; National Assessment Governing Board, 2010; National Governors Association, 2007a; New Commission on the Skills of the American Workforce, 2007; Partnership for 21st Century Skills, 2008; Seltzer & Bentley, 1999; The Conference Board, Corporate Voices for Working Families, Partnership for 21st Century Skills, and Society for Human Resource Management, 2006).

The broad ranging value of teaching our children, youth, and adults to be creative has been recognized by Hennessey & Amabile (2010):

> Educators, parents, employers, and policy makers realize all too well that it is only with creativity that we can hope to address the myriad problems facing our schools and medical facilities, our cities

> and towns, our economy, our nation, and our world. Creativity is one of the key factors that drive civilization forward. (p. 570)

Florida (2002) stated that a creative ethos—"the fundamental spirit or character of a culture"—is fueling spectacular continuous change "because new technologies, new industries, new wealth and all other good economic things flow from it" (p. 21). Friedman (2011) commented on what employers are looking for in new employees today: "people who not only have the critical thinking skills to do the value-adding jobs that technology can't, but also people who can invent, adapt and reinvent their jobs every day, in a market that changes faster than ever" (para. 4).

Based on a survey of managers and other business executives, the American Management Association (2010) concluded that creativity along with critical thinking, collaboration, and communication skills would be better taught to students who are likely more open to progressive ideas than veteran employees who have set work routines and habits. Lichtenberg, Woock, and Wright (2008) reported results of their research that indicated employers preferred hiring workers who were creative thinkers to the prospective hires with technical skills. The Conference Board, et al. (2006) concluded from their survey of corporate executives that although creativity/innovation has increasing importance for new entrants to the workforce, most high school and two-year college graduates were deficient in this applied skill.

Technological progress has occurred by designing our environment to meet our biological, communication, energy and power, transportation, and production needs and wants. Design is omnipresent ranging from graphic, to architectural, to engineering, to industrial, and to many other branches of the human-made world. The New Commission on the Skills of the American Workforce (2007) declared "The American economy will not succeed . . . unless people at every level of our society are accomplished original designers. And that will not happen until design–good design–plays a much larger role in the American curriculum" (p. 30).

PROPERTIES AND RELATIONSHIPS OF CREATIVITY AND DESIGN

The initial three chapters of this Yearbook examined the properties and relationships of creativity and design. Highlights of each of these chapters and a review of additional related literature follows.

Chapter 1: Context for creativity and design in technology education by Scott Warner. Creativity and design have provided a symbiotic (mutually beneficial) relationship in serving as important mental tools in the biological functioning and evolution of humans. These tools have contributed to the study of technology in a dynamic and progressive technology education curriculum. Design has usually been associated with technical drawing and the aesthetic (pleasing or beauty) qualities of resulting products and systems. The more extensive and holistic use of creativity and design in the study of technology began with the Arts and Crafts movement in the late 1800s, continued with progressive industrial arts in the 1900s, and is manifested in a variety of technology and engineering education curriculums of the 21st century.

Related context literature. What creates creativity? Dyer, Gregersen, and Christensen (2009) answered this question in their research of identical twins that lead separate lives immediately after birth. These studies "indicate that our ability to think creatively comes one-third from genetics; but two-thirds of the innovation skill set comes through learning—first understanding a given skill, then practicing it, experimenting, and ultimately gaining confidence in one's capacity to create" (p. 3).

Education is, therefore, a major contributor to the development of human creativity. Spendlove (2008) said "The inclusion of opportunities to engage in creative processes within a child's experiences provides a powerful force for children to use their creative ability to have ownership over their environment" (p. 14). Florida (2007) stated "schools need to be vehicles for enhancing and mobilizing the creative capacities of all our children so that the tinkering of today can be translated into the creative advancement of tomorrow" (p. 254).

The properties of individual and collective creativity that result in a *novel* product, process, or system have been explained with different approaches. The individualist approach associates creativity with psychological characteristics (e.g., divergent thinking) exhibited by the creative person. The sociocultural approach further validates human creativity based on its *appropriateness* within the context of sociology (social system), anthropology (culture), and history (time).

The Conference Board, et al. (2006) recommended the development of more project-based skills for new high school and college graduate entrants into the 21st century workforce, because a minimum of half of the U.S. jobs required participation in projects. Frysh (2011) recognized the value of project-based learning by Finland's students who after studying multiple subjects and their relationships with the project approach earned the overall top test rankings on the Program for International Student Assessment. Finnish students ranked second in science, third in mathematics, and second in reading on these tests administered by the Organisation for Economic Co-operation and Development (Levine, 2011).

In 1983, Amabile reported research evidence for positive social influences on creativity. Enhanced creativity had occurred after providing people the freedom to choose how to perform a task, offering an unexpected reward for doing a required task, modeling the behaviors of creative mentors, establishing stimulating physical environments, engaging children in play and fantasy before planned tasks, and detaching interpersonally to enable more student independence and reduced external control.

Another contributing factor to being creative in the sociocultural environment was one's intrinsic motivation (Amabile, 1996; Hennessey and Amabile, 2010). This personality characteristic provided the natural desire or excitement to participate because of interest, enjoyment, curiosity, positive challenge, or perceived fulfillment. It appeared to be most crucial during the novel thinking stages of creativity that involved identifying problems and generating ideas. Amabile (1996) stated that creativity was maximized when a person's subject matter skills overlapped this individual's highest level of intrinsic motivation and novelty thinking activities.

In team settings, Hennessey and Amabile (2010) encouraged team leaders to assist individual member actions, provide constructive comments, and recognize quality work to increase creativity. Offering extrinsic synergistic motivators (e.g., confidence builders, resource availability, and clear deadlines) facilitates the creative process, especially during the incubation and verification stages, by staying engaged and completing the project. However, when the leader checks the member's work too often, does not provide needed information, and avoids resolving difficulties, creativity declines.

In *Technology for all Americans*, the International Technology Education Association (ITEA) posited "Technology is the result of human innovation—creativity, knowledge, and skills. Ingenuity depends on a firm understanding of existing technology and the ability to conceive something that does not currently exist" (1996, p. 31). "The designed world," which is frequently documented throughout *Standards for Technological Literacy* (*SfTL*; ITEA, 2007), recognized the contrived environment that humans have created. The products, processes, and systems in this world represent the technological developments that have resulted from the creative thinking and doing of people. The extensive inclusion of "engineering" in the *SfTL* and the expanded name and mission of the ITEA to include engineering education vis-a-vis International Technology and Engineering Educators Association in 2010 reinforced the rationale for technological creativity and design to have an engineering context.

Chapter 2: Defining creativity and design by Barry Yatt and Joseph McCade. The numerous definitions of creativity can be classified according to the person who is creative or the response of being creative. Abstract creativity is associated with artistic self-expression while applied creativity is defined by its outcomes and impacts for the natural and contrived environments. Creativity employs divergent thinking in which brainstorming—generating numerous responses without initial criticism—has demonstrated value in improving creative quality. Design is the creative act of technological problem solving. The design process engages both the human intellect (left brain) and intuition (right brain) to process information and trigger inspiration in creating solutions to technological problems.

Related definition literature. Several of this Yearbook's authors defined creativity and/or design to provide the context for the theme of their respective chapters. Further elaboration on these definitions along with qualities for their achievement will now be examined.

Definitions for these terms as they were retrieved from Answers.com are

Creativity: "Ability to produce something new through imaginative skill, whether a new solution to a problem, a new method or device, or a new artistic object or form. The term generally refers to a richness of ideas and originality of thinking" (*Britannica Concise Encyclopedia*, 1994-2010).

Definitions in the creativity literature focus on the creative person (personality characteristics), creative process (problem solving), creative product (observable outcome or response), or creative place (social-cultural environment). Cognitive approaches and operational stages are necessary for developing and advancing creativity. In the designed world, creativity is the process of contriving an idea, product, service, solution, or system that is novel, unique, and of value. Originality, appropriateness, and visual imagery are necessary criteria. For this concluding chapter, *creativity is defined as the ability to conceptualize knowledge and practices to add novel value*.

Design: "To plan out in systematic, usually graphic form . . . . To create or contrive for a particular purpose or effect . . . . To create or execute in an artistic or highly skilled manner" (*American Heritage Dictionary*, n.d.).

Design is the interface of technological knowledge mediated by the sciences (inquiry), arts (aesthetics), and humanities (ethics). Technological design leads to new knowledge (technological literacy) and practices (technological capability) as the designer or engineer synthesizes and reduces conceptual knowledge to practice. Heuristics assist in making necessary and appropriate decisions (Lewis, 2007). For this chapter, *design is a heuristic (rule of thumb strategies) or iterative (recurring and repeated) process of generating systematically a creative response for a given problem or challenge*.

How is innovation related to creativity and design? Whereas creativity is the ability of recognizing new patterns and possibilities to generate a new and beneficial idea and design is the process of generating a creative response that meets identified criteria within given constraints, *innovation is the implementation of creativity and design for economic benefit*. In an entrepreneurial context, creativity comes up with the big idea, design provides practical value, and innovation is the successful production and marketing of the creative design by an enterprise (The New Commission on the Skills of the American Workforce, 2007; Govindarajan, 2010).

In a six-year study, Dyer, Gregersen, and Christensen (2009) surveyed executives, innovators, and inventors to determine the influences on their creativity. These researchers determined four "doing" habits and one "thinking" habit of the most innovative entrepreneurs. The four skills that provided the inputs or resources for the creative product or outcome included *questioning*, *observing*, *experimenting*, and *networking*. Diverse experience and knowledge gained from these habits increased the opportunities for more unique and imaginative ideas. For example, actively asking "why" and "why not" questions, observing potential uses of the product or service, learning from mistakes, and collaborating with creative people advanced creativity for innovation. The thinking skill that the researchers called *associating* provided the connections leading to novel ideas and solutions. This associational cognition was the synthesis or new directions that these innovators made by connecting supposedly unrelated questions, ideas, or problems (Dyer, Gregersen, & Christensen, 2011).

Creativity is a valuable attribute in both identifying and solving problems in our technological society. Systematically approaching solutions to these problems and drawing upon a diversity of knowledge should enable quality outcomes. Schools, therefore, should be preparing learners to be creative problem solvers with appropriate attention to problem identification and problem solutions. When The Conference Board and Americans for the Arts, working with the American Association of School Administrators, surveyed 155 U.S. business executives (employers) and 89 school superintendents and school leaders (superintendents) to determine the skills and abilities that cultivate creativity, the school superintendents selected problem solving as the top ranking skill that employers would be seeking in new employees; however, the employers rated problem identification as being more important (Lichtenberg, Woock, & Wright, 2008). It is noteworthy that superintendents ranked problem solving twice as high as the employers who ranked it, and the reverse was true for problem identification.

Sawyer (2006) stated that problem finding, in which the problem is not initially known but emerges from the work being conducted, often leads to significant creative advances. Good problem finders are good at inquiry and asking revealing questions. Lichtenberg, Woock, & Wright (2008) also presented data showing that while 37% of the employers in The Conference Board survey identified that students should be comfortable with "no right answers," only 14% of the superintendents identified this skill as an indicator of creativity. Thus, there appears to be a need for schools to engage students more in solving unstructured and ill-defined problems that require problem identification, divergent thinking, and multiple potential solutions to prepare for successful employment.

Cross (1982) identified the value of design products as a salient area of knowledge for studying design. Looking at products of the past was a good way of determining how products were designed. Osburn (1948) exemplified this practice in his book entitled *Constructive Design* in expressing his philosophy as “Designing is a process of seeing the need, analysing the functions, knowing the materials, understanding the processes of forming, and in all these steps of developing sensitivity to beauty” (p. v). He continued by stating “The power of thinking–planning–designing– (sic) is a necessary part of the learning process which may, like other skills, be taught and improved. The discerning teacher will note that the designing process follows the steps in reflective–thinking” (p. vii).

SfTL recognized design as crucial for technological problem solving and the development of learner cognitive and procedural knowledge for both design creation and innovation as essential for technological literacy (ITEA, 2007). Within the Engineering by Design *SfTL*-based curriculum, for example, technological design has been identified as a teaching/learning strategy for learning problem identification and problem solving by following authentic procedures employed by engineering teams (ITEA, 2009).

Engineering design is an iterative, systematic process for solving technological problems (International Technology Education Association, 2007; National Assessment Governing Board, 2010; Committee on Conceptual Framework for the New K-12 Science Education Standards, 2011). Sawyer (2006) posited that this iterative process consists of numerous mini-insights over time with ongoing conscious elaboration. The iterative cycle (see Table 1, next two pages) includes identifying engineering problems, preparing and applying models, conducting investigations, deriving the meaning of data, applying mathematics, determining potential solutions, selecting the optimal solution, and communicating the benefits and trade-offs of the new or improved technology. Ongoing analysis, decision-making, refinement, and collaboration occur throughout the process (Committee on Conceptual Framework for the New K-12 Science education Standards, 2011, p. 8-2).

Table 1. Iterative Cycle of Design Practices in Engineering

1. Defining Problems and Asking Questions **Engineering** begins with a problem, need or desire that suggests an engineering problem that needs to be solved. Engineers ask questions to define the engineering problem, determine criteria for a successful solution, and identify constraints.
2. Developing and Using Models **Engineering** makes use of models and simulations to analyze existing systems so as to see where flaws might occur or to test possible solutions to a new problem. Engineers also call on models of various sorts to test proposed systems.
3. Planning and Carrying Out Investigations **Engineers** use investigation both to gain data essential for specifying design criteria or parameters and to test their designs. . . . engineers must identify relevant variables, decide how they will be measured, and collect data for analysis. Their investigations help them to identify how effective, efficient, and durable their designs may be under a range of conditions.
4. Analyzing and Interpreting Data **Engineers** analyze data collected in the tests of their designs and investigations; this allows them to compare different solutions and determine how well each one meets specific design criteria—that is, which design best solves the problem within the given constraints.
5. Using Mathematics and Computational Thinking In **engineering,** mathematical and computational representations of established relationships and principles are an integral part of design. . . . simulations of designs provide an effective test bed for the development of designs and their improvement.

6. Constructing Explanations and Designing Solutions **Engineering design,** a systematic process for solving engineering problems, is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, esthetics, and compliance with legal requirements. There is usually no single best solution but rather a range of solutions. Which one is the optimal choice depends on the criteria used for making evaluations.
7. Engaging in Argument from Evidence In **engineering,** reasoning and argument are essential for finding the best possible solution to a problem. Engineers collaborate with their peers throughout the design process, with a critical stage being the selection of the most promising solution among a field of competing ideas. Engineers use systematic methods to compare alternatives, formulate evidence based on test data, make arguments from evidence to defend their conclusions, evaluate critically the ideas of others, and revise their designs in order to achieve the best solution to the problem at hand.
8. Obtaining, Evaluating, and Communicating Information **Engineers** cannot produce new or improved technologies if the advantages of their designs are not communicated clearly and persuasively. Engineers need to be able to express their ideas, orally and in writing, with the use of tables, graphs, drawings, or models and by engaging in extended discussions with peers. . . . new technologies are now routinely available that extend the possibilities for collaboration and communication.

Note. Adapted from “A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas” by Committee on a Conceptual Framework for New K-12 Science Education Standards, Board on Science Education, Division of Behavioral and Social Sciences and Education (2011), pp. 3-29 – 3-32. Copyright 2011 by the National Research Council of the National Academies.

Dym, Agogino, Eris, Frey, and Leifer (2005) stated that engineering design requires both convergent and divergent thinking. Convergent thinking requires analytical inquiry of mathematical and scientific knowledge to arrive at a verifiable answer. Divergent thinking generates multiple unverified alternative concepts from which to synthesize a design.

The knowledge of practices, called *praxiology*, has been a critical component of teacher education. Recent attention to creative thinking and design praxiology, which is demonstrated through performance-based action and conduct, has received elevated attention in the assessment of technological and engineering literacy. The National Assessment Governing Board (2010) for the 2014 National Assessment of Educational Progress has stated that critical ways of thinking and reasoning, called practices, will be assessed when students demonstrate their understanding of technological principles (e.g., creative thinking for technological innovation), solve engineering design problems, and communicate and collaborate on achieving goals of technological design.

The Committee on a Conceptual Framework for New K-12 Science Education Standards (2011) also used "the term 'practices' . . . to emphasize that engaging in scientific investigation [and engineering design] requires not only skill but also knowledge that is specific to each practice" (p. 2-5). This Committee acknowledged the iterative cycle of design as having the most educational value for applying science knowledge and participating in engineering practices.

Chapter 3: The many forms of creative expression by David Stricker. There are many approaches and opportunities for understanding, recognizing, and fostering creativity in a democratic teaching and learning environment. A growing body of seminal research on creativity is providing a solid foundation for the development and implementation of creativity and design in technology education. Some technology educators may need to expand their professional development and risk-taking to engage their students in these learning opportunities. Creative, design-based competitions are widely available for inclusion in the technology education curriculum for all students.

Related creative expression literature. Both explicit language-based knowledge and tacit experience-based knowledge contribute to creative expression. Explicit knowledge is declarative knowledge consisting of facts, concepts, principles, skills, etc. that are understood and can be communicated verbally. Tacit knowledge, on the other hand, is often learned through experience and by doing and may not be consciously realized making it difficult to transfer to another person. Explicit or factual knowledge may be described as "know-what" in comparison to tacit or procedural knowledge that is "know-how."

Creativity occurs within work as one solves problems that arise in accomplishing the duties and responsibilities of a task or job. Knowledge is gained through physical activity as one learns with tools and techniques, works systematically to solve real problems, responds and adapts to the environment, values safe and efficient work habits, applies kinesthetic skills to assess situations and accomplish tasks, visualizes and implements designs, and combines aesthetics with function. Rose (2004) stated

> . . . the world of everyday work provides a rich display of the kinds of mental activity long valued by those who study human thought. The big difference between the psychologist's laboratory and the workplace is that the processes and activities are not isolated but blend, embedded in the real-time flow of work, in all its rituals, routines, distractions, and social complexity. (p. 201)

Engineering design is the primary type of technological design identified in *Standards for Technological Literacy* (ITEA, 2007). Minimal reference is given by name to such other traditional components of technology education as graphic (visual) design, architectural design, and industrial design. Empirical research has recognized that different types of designers think differently in the way that they approach solving technological problems. For example, Lawson (1980) identified a difference between engineers and architects in the process that they use in problem solving. Engineers used a problem-based analytical process requiring convergent thinking to determine an optimal solution; whereas, architects followed a solution-based synthesis approach to arrive at an appropriate solution.

The Technology Student Association, FIRST Robotics, Odyssey of the Mind, and Real World Design Challenge provide numerous competitions for creative and design thinking. Research suggests that the creative performance for both individual and team events have been enhanced when the participants were intrinsically motivated (voluntarily participating because of interest and the challenge) as opposed to a required class requirement or other external reason. Sawyer (2006) also noted that when the performance requires improvisation, collaboration, and communication, the contestants tend to be more creative when an audience is present.

HUMAN CAPABILITIES FOR CREATIVITY AND DESIGN

Chapters 4–6 of this Yearbook examined the capabilities of people for creativity and/or design. Highlights of each of these chapters and a review of additional related literature follows.

Chapter 4: Developmental stages of humans and creativity by Gerald Day. Technology teachers' knowledge of the level of their students' development is critical in determining learner capacity for creativity. Favorable and unfavorable outcomes are associated with the different stages of human development. The human growth and development approach enables program preparation to promote creativity and student progress throughout the school years. Planning appropriate creativity strategies to meet student physical, intellectual, emotional, and social needs will promote effective technology and engineering education.

Related human developmental stages literature. The National Assessment Governing Board (2010) stated that the technology and engineering literacy assessment that it is developing for implementation in 2014 will be appropriate for the developmental level of the students at Grades 4, 8, and 12. All students will be examined on core principles of engineering design. Student knowledge and skill will be measured according to the school levels as follows: "Elementary–simple yet systematic design challenges; intermediate–more elaborate engineering design process (i.e., problem definition, use of prototypes, testing and iteration, trade-offs); and high school (i.e., deep understanding, broad array of design skills, including optimization)" (p. A-29).

Chapter 5: The creative brain by Kenneth Heilman. Various qualities of the human brain contribute to the creativity of students and teachers. Modern medical technology, especially electroencephalogram and functional imaging, has enhanced the understanding of the various parts and divisions of the human brain. Domain specific knowledge and spatial reasoning are necessary for creativity. Skilled performances rely on procedural memories, which are possibly *not* needed for creativity. Disengagement (separating from existing ideas, practices, and beliefs) followed by divergent thinking is necessary for creativity. Both hemispheres of the brain mediate skills and knowledge necessary for most creative acts. Creative expression is enabled by the biological nature of the brain and through nurture provided by exposure to knowledge and experiences that foster curiosity, divergent thinking, and novelty.

Related creative brain literature. A gene for creativity is not coded in humans and a trait for creativity is not specifically located in the human brain. Instead, creative ability is a composite function that systematically draws upon different areas within both the left and right hemispheres (Sawyer, 2006). The left side of the brain enables analysis, logic, and sequence while the right side handles synthesis, context, and aesthetics (Pink, 2006). Left brain learners focus on details, and right brain learners see the big picture.

Sawyer (2006) stated that most psychologists recognize preparation, incubation, insight, and verification as the four stages of creativity. Preparation involves internalizing domain knowledge, which is the primary purpose of formal education. Incubation involves idea associations, mental cross-fertilization, and concept combinations under the surface of consciousness typically during idle time or when attention is diverted to an unrelated activity or a different problem. Insight occurs when mental structures that were developed in incubation become conscious and are recognized by the creator. Verification requires evaluation of the insight, which Sawyer called a raw spark, to determine its worthiness and then elaboration, which draws upon the creator's domain knowledge and skills, to develop a working outcome.

Hennessey and Amabile (2010) noted that advanced technology in brain imaging and the access to this equipment by researchers are largely responsible for learning about the brain's creativity function. Although the potential is promising, much more needs to be accomplished before the creative process can be recorded as it occurs in the brain.

Chapter 6: Creativity, innovation, and design thinking by Meredith Davis. Knowledge of the origin, components, contexts, and influences of design thinking are important to understanding and promoting creativity and innovation in general education. All learners should know and experience the open-ended, situated, responsive, values-laden, integrative and holistic, and authentic characteristics of good design. They should be educated about the linkages between the designers' perceptions of design problems and the properties of the creative outcomes. School cultures should honor the value of quality creative ideas and the production of objects having good design to meet increasingly complex problems, rapid change, and user desires.

Related creativity, innovation, and design thinking literature. Employers have indicated that entry level employees are deficient in creativity/innovation, yet it is one of the most needed applied skills for success in today's workplace (The Conference Board et al., 2006). Design thinking is an avenue for developing creativity and innovation skills in pre-kindergarten through twelfth grade (P-12) learners to assist them in being sensitive to the contexts of real-world problems, generating insights and solutions, and logically analyzing and modifying the solutions to appropriately align with the contexts of the problems. This solution-based thinking process focuses on the goal or desired outcome at the beginning and then works backwards to explore aspects of the problem and potential resolutions to create an optimal solution. The solution is arrived through synthesis by ideating numerous potential resolutions (divergent thinking) and then combining appropriate ideas into a coherent design (convergent thinking).

PEDAGOGY AND ENVIRONMENTS FOR CREATIVITY AND DESIGN

The intent of Chapters 6–10 was to explain avenues for planning, implementing, and assessing instruction and programs for developing creativity and design abilities in P–12 learners. Highlights of each of these chapters and a review of additional related literature follows.

Chapter 7: The knowledge and skills of creativity and design by Todd Kelley and Martin Rayala. Individuals with developed creativity and design skills have the capacity for higher creative expression. Understanding how expert designers think can enhance the breadth and depth of a learner's knowledge. Cognitive capabilities and meta-cognitive skills, such as moving beyond conceptual fixedness, are salient thinking processes. Sketching, mechanical drawing, visualizing, conceptual modeling, and prototyping are valuable design skills. Knowing "what" and "how" via a holistic approach to engineering design and problem solving are important content and skills to be taught in technology education.

Related knowledge and skills literature. Middleton (2008) concluded from his case study involving an advanced beginner design student, a competent architect, and an expert architect that the capability of solving an architectural design problem was facilitated by visualization for each level of design expertise. The production of visual mental images facilitated problem exploration, solution generation, and executive control (process management) along with these procedures stimulating the development of visual mental images. The collected data also revealed that the designers with more expertise generated solutions earlier and that solution generation initiated visual mental images more often than the other two procedures.

Seltzer and Bentley (1999) concluded from their case study and other research that creativity occurs as a result of the student interacting with the learning environment. The primary characteristics of settings that promoted creativity are as follows:

- **Trust:** secure, trusting relationships are essential to environments in which people are prepared to take risks and are able to learn from failure.
- **Freedom of action:** creative application of knowledge is only possible where people are able to make real choices over what they do and how they try to do it.
- **Variation of contexts:** learners need experience applying their skills in a range of contexts in order to make connections between them.
- **The right balance between skills and challenge:** creativity emerges in environments where people are engaged in challenging activities and have the right level of skill to meet them.
- **Interactive exchange of knowledge and ideas:** creativity is fostered in environments where ideas, feedback and evaluation are constantly exchanged, and where learners can draw on diverse sources of information and expertise.
- **Real world outcomes:** creative ability and motivation are reinforced by the experience of making an impact – achieving concrete outcomes, changing the way that things are done. (p. ix)

Chapter 8: Physical environments for creativity and design by Kerri Myers and Milton Shinberg. Physical surroundings should be established to support the teaching/learning strategies and desired outcomes of a standards-based curriculum with a focus on creativity and design. Varying light illumination, slightly cool temperature, and a flow of fresh air encourages creativity. Typically, higher saturated colors energize while subdued colors calm the students. Flexible space configurations and ergonomic furnishings can encourage creative thinking and design activities. Abundant available information and material resources have a highly positive impact on technological problem solving. Also, a class size of 25 students or less enhances learning accommodations, knowledge retention, creative expression, and problem-solving abilities.

Related physical environments literature. Guiding principles of facility planning to enhance creativity and design learning include flexibility, aesthetics, diversity, proximity, and integration (Gemmill, 1989; McAlister & Krueger, 2000). Flexibility and transformability of walls, equipment, furniture, and utilities are keys to supporting the existing curriculum and being adaptable to future trends. Aesthetics based upon choice of color, appropriate selection of materials, location of windows, selection of artwork, and inclusion of plants and signage can have positive psychological, emotional, and communication benefits. Diversity of information and tool resources often adds interest and stimulates the generation of a broad range of creative ideas. Proximity of centers, tools, and materials enhance themes, efficiency, and the flow of learning. Integration of multiple subjects such as science, technology, engineering, and mathematics (STEM) enables connections and authentic experiences.

Physical environments to enable learning for creativity and design should have the resources to encourage entrepreneurship, the use of automation such as computers to gather and analyze information, research and experimentation, collaboration with culturally diverse team members, and communication with spatially separated people connected by networks (Apple, 2008; National Governors Association, 2007b).

Chapter 9: Cultural environments for creativity and design—A case study by Jennifer Baker. In this case study the Charter High School for Architecture + Design (CHAD) exemplified a micro-culture devoted to student immersion in creativity and design. CHAD employed block scheduling; the design process across the curriculum; teacher and student collaboration; a studio environment for exposure to new materials, tools, processes, and design concepts; along with portfolios and exhibitions for performance assessments. This school in an urban macro-culture serves as a design-focused general education model that employs the constructivist approach to prepare individuals for change and the creative economy.

Related cultural environments literature. The constructivist approach of pedagogy employs student initiative and creative thinking to discover knowledge and make knowledge. Using design as the teaching/learning strategy provides the avenue for higher level cognitive processing required in today's transition from the knowledge era to the innovation (conceptual) era (Seemann, 2002).

Kimbell and Stables (2008) stated that the design project/portfolio is a valuable avenue for the learner to make explicit his or her creative thinking and decision-making processes in designing a product and for the teacher to structure the design process to enhance student achievement of technological creativity and design skills. The integration of an assessment framework of devices and prompts throughout the planned learning process can guide the development of learner capability. This ongoing process of gathering design evidence as indicators of capability maintains the integrity of the activity and contributes to the holistic assessment of student performance.

> The activity structure must – above all else – be an authentic and valid representation of design & technology. Learners must be able to develop their ideas responsively, driven by design intentions and in the process leaving behind a trace of where they have been. This trace enables us to gather insights into what these intentions were and how they shaped the emerging solution. (Kimbell & Stables, 2008, p. 50)

Chapter 10: Curriculum, instruction, and assessment for creativity and design by Gareth Hall. What is taught, how it is learned, and the way it is measured determines learner technological literacy and capability. Designing, facilitating, and assessing technology education so that learners use their knowledge to creatively solve authentic, open-ended design challenges provides a compelling contribution to the school curriculum. Such an approach integrates the currently dominant academic focus on analytical, convergent knowledge with synthetic, divergent knowledge that is central to the development of creative and design abilities. This new paradigm focuses on the intrinsic value of creativity and "designerly" thinking and doing, which is needed to prepare learners for living and working in the Conceptual Age of the 21st century.

Related curriculum, instruction, and assessment literature. Cross (1982) posited a third culture, design, to join the science and humanities cultures as areas of human knowledge within general education for all people. Design is a study of the human contrived world that employs "modeling, pattern formation, and synthesis" (p. 221), to provide "practicality, ingenuity, empathy, and a concern for 'appropriateness'" (p. 223). As such, it would contribute to the intrinsic aim (for the sake of knowing) of developing one's intellect and character by adding valuable knowledge via deliberate cognitive processes of understanding.

Huitt (2007) postulated “The demands of the Conceptual Age, incorporating, amplifying, and adding to those of the Information Age, require a decentralized approach to educational reform that balances creativity with a need for accountability” (p. 9). Reflecting on criticism of standardized testing of academic standards, Baer and Garrett (2010) stated that creativity requires not only divergent thinking, but also evaluative and convergent thinking along with content knowledge and skills. Students who learn more content knowledge should be better prepared for creative thinking and more creativity often stimulates the need for more content knowledge. These authors recognized the benefit of teaching for both creativity and content knowledge:

> Teaching for creativity and detailed required content standards can coexist quite comfortably and, although they may seem at times to be working at cross purposes (and, indeed, this is sometimes the case), they just as often work synergistically, such that teaching for creativity helps meet content standards goals and teaching detailed content knowledge can reinforce and enhance student creativity. (p. 7)

Creativity requires deep thinking and technical know-how to make the connections of diverse knowledge and the identified task or challenge. The creative person synthesizes ideas, which is “the ability to see patterns where others see only chaos” (New Commission on the Skills of the American Workforce, 2007, p. 30).

Middleton (2005) added that

> designing, inventing, and the related activity of design and technology learning are: complex activities requiring higher-order thinking; where that higher order is facilitated not primarily by abstract thought but by visual mental imagery and the manipulation of concrete materials; in situations and contexts that are meaningful to the designer. (p. 66)

Technological creativity is a process requiring cognitive (knowledge), psychomotor (actions), and affective (dispositions) abilities. This process is conceptual, physical, and social. Taxonomies for these three domains can assist educators in classifying behavior and performance for holistic learning.

The Bloom’s Taxonomy Revised of cognitive behaviors adds precision to the development of behavioral objectives and goals, performance strategies, and formative and summative questions

(Anderson & Krathwohl, 2001). It is structured with cognitive process categories having increasing complexity (i.e., Remember, Understand, Apply, Analyze, Evaluate, and Create). Nineteen specific cognitive processes are associated with the six umbrella categories to achieve both retention and transfer of knowledge. The Create category represents synthesis cognition that is needed for creativity and design.

Mayer (2002) explained the rationale of the revised Bloom's taxonomy of the cognitive domain as follows:

> *Create* involves putting elements together to form a coherent or functional whole: that is, reorganizing elements into a new pattern or structure. Objectives classified as *Create* involve having students produce an original product. . . . Thus, the creative process can be thought of as starting with a divergent phase in which a variety of possible solutions are considered as the student attempts to understand the task (generating). This is followed by a convergent phase, in which a solution method is devised and turned into a plan of action (*planning*). Finally, the plan is executed as the solution is constructed (*producing*). Not surprisingly, then, *Create* can be broken down into three cognitive processes: *generating, planning, and producing.* (p. 231)

The six major categories of this taxonomy differ in their complexity, with categories overlapping one another (Krathwohl, 2002). For example, designing could be identified in both the *analyze* and *create* (synthesis) categories with the expectation that students will need to analyze conceptual knowledge before they design a solution based on that conceptual knowledge.

Simpson (1972) developed a seven-level taxonomy for the psychomotor domain to assist classification of performance objectives and goals involving motor skills, tool and material manipulation, or neuromuscular abilities. This taxonomy assists in clarifying, analyzing, and communicating the level of difficulty and sequence of actions. Thinking (cognition) and a willingness to participate (affect) are co-requisites for developing and demonstrating the various motor abilities and skills. Herschbach (1975) pointed out that identifying the psychomotor behavior is to enable convenience, not necessarily scientific precision. The two highest levels of "adaptation" and "origination" appear to be especially germane to developing skills and abilities for creativity and design. Adaptation is "altering motor activities to meet the demands of new problematic situations requiring a physical response," and origination is "creating new motor acts or ways of manipulating materials out of understanding, abilities, and skills developed in the psychomotor area" (p. 54).

PROFESSIONAL DEVELOPMENT OF TECHNOLOGY AND ENGINEERING EDUCATION TEACHERS

Chapter 11 of this Yearbook examined the preservice and inservice professional development of teachers for creativity and design. Highlights of this chapter and a review of additional related literature follows.

Chapter 11: Professional development of teachers to support creativity and design in the technology education classroom by Marie Hoepfl. Resources are available to teachers for recognizing, stimulating, and facilitating creativity in technology education. Professional development enables teachers to understand design as a process, develops their competence in applying design approaches, and connects design activity with curriculum goals and standards. Techniques for achieving these design-based professional development goals includes replicating model pre-service teacher education programs (e.g., SUNY–Oswego as described by John Belt), studying model in-service programs (e.g., UK Nuffield Project), pursuing graduate studies and summer workshops, and investigating such relevant resources as the Cooper-Hewitt National Design Museum, the *International Journal of Technology and Design Education*, or the U.S. Patent and Trademark Office.

Related professional development literature. Several creativity enhancement programs, such as Creative Problem Solving, Odyssey of the Mind, Talents Unlimited, and Synectics, are available for schools (Amabile, 1996; Baer & Garrett, 2010). The development of divergent thinking, typically with the use of brainstorming or a related variant, is the primary approach. The deferment of judgment when generating ideas has been shown to enhanced creativity.

Hennessey and Amabile (2010) stated that thoughtfully designed and delivered programs often increase creativity with higher gains in the programs that have authentic exercises to develop cognitive skills and heuristics for using these skills. Computer-based divergent thinking training programs have demonstrated significant gains for "ideation fluency" (generation of ideas; p. 576) but not for originality of ideas.

After examining numerous research studies on creativity training programs for businesses, Sawyer (2006) noted the caveat that there is minimal scientific evidence that any of these approaches lead to significant creative output. Acknowledging the difficulty of measuring creativity, he noted sociocultural influences likely impact the success of many of these approaches. Sawyer reflected ". . . creativity is hard work; creativity is usually an incremental step beyond what has come before; creativity often emerges from a team, not a solitary individual; and increasing creativity often requires substantive organizational change" (p. 301).

CONCEPTUAL FRAMEWORK FOR CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

A synthesis of the research and perspectives presented in this Yearbook provides the bases for a conceptual framework for creativity and design in technology and engineering education. This model summarizes the theoretical basis for creativity and design plus describes guidelines for educators and learners to apply the respective knowledge, practices, and dispositions (see Table 2, next two pages).

Creativity is defined as the ability to synthesize knowledge and practices to add novel value. Design is an iterative/heuristic process of generating systematically a creative response for a given problem or challenge. Innovation is the implementation of creativity for economic benefit by successfully producing and marketing the designed product, service, or other outcome.

The goal of creativity and design in technology education is to determine novel answers to questions, fresh ideas for tasks, and new value-added solutions to problems to meet the technological desires and needs of people. The synergy between thinking (mind) and doing (reality) is the crux of the value-added capability provided by holistic learning. It serves as a rationale for learning both the concepts and the practices of technology and engineering to develop technological literacy and technological capability.

Table 2. Conceptual Framework for Creativity and Design in P-12 Technology and Engineering Education

Definitions

- Creativity: Ability to conceptualize knowledge and practices to add novel value; inherent capacity in everyone
- Design: Heuristic and iterative process for generating systematically a creative response for a given problem or challenge; includes criteria and constraints
- Innovation: Implementation of creativity for economic benefit by successfully producing and marketing the designed product, service, or other outcome.

Goal of creativity and design in Technology and Engineering Education

- Educate learners to understand, apply, manage, and assess knowledge, practices, and dispositions for creating and designing the contrived environment to meet individual, societal, and cultural desires and needs.

Knowledge: Core concepts and principles (Technological literacy)

- Technology and engineering domains
- Broad disciplinary knowledge (sciences, arts, and humanities)
- Explicit and tacit
- Creativity properties and relationships to design and innovation
- Design attributes (elements and principles)
- Design processes (goals, heuristics, approaches, and environments)
- Engineering, architectural, industrial, graphic, and other applications

Practices: Ways of thinking, reasoning, and doing (Technological capability)

- Creativity: preparation, incubation, insight, evaluation, and elaboration
- Design: iterative, systematic, creative, authentic, and experiential
- Innovation: questioning, observing, networking, experimenting, and connecting disparate subjects
- Designerly thinking and reasoning: divergent and convergent; creative and analytical; and deductive and inductive
- Design processes: Identifying and defining problems, developing and using models, investigating, analyzing, applying information and technology, designing solutions, and communicating results
- Observe and question potential consumers of creative design
- Apply rational and heuristic approaches systematically and in different contexts
- Utilize concrete materials and techniques in situations and contexts meaningful to the designer
- Employ metacognition for efficient and effective learning

• Generate new ideas, exchange feedback, and contribute as team players • Work with ideas, materials, and techniques to inspire creativity • Engage in verbal (language) and tacit (experience) representations of knowledge • Think visually by sketching, drawing, visualizing, modeling, and prototyping • Use web-based information and communication technology • Participate in project-based learning in individual and team contexts • Develop and assess electronic portfolios • Judge creativity of student designed and produced products
Dispositions: Beliefs to excite creativity and enable design (Technological attitudes) • Focus on the goal of being creative • Environment of empathy, trust, risk-taking, learn from failure, and collaboration • Acquisition of knowledge and skills at the level needed to meet design challenges • Diversity of knowledge and contexts contribute to novel ideas and solutions • Experiment with ideas, materials, and processes • Creativity usually requires time and perseverance • Creative designers are motivated by intrinsic rewards • Creativity often follows a period of play or diversion from focus on the creative task
Preparation for Conceptual Age of Creativity, Design, and Innovation • Clear and articulated vision • Understanding elements of change • Demonstration of knowledge, practices, and dispositions for creativity and design • Continuing education for educators, parents, and community members

Creativity and design knowledge. The technological literacy component of creativity and design is knowledge comprised of core concepts and principles. Creativity knowledge includes explicit verbal content learned through structured schooling and tacit knowledge that is drawn from experience and through the senses while being actively engaged in one's environment. Knowledge and associated information serve as the tools and materials for creativity. Design knowledge consists of attributes (i.e., elements and principles) and stages of design—often called the design process—that are appropriate for the application (context) of technological design. Technological design occurs not only in such professional contexts as engineering, architecture, graphic design, product design, and a host of other design-based fields, but in everyday life as people make decisions and take actions to do such things as repair the lawn mower, paint a room, or use a cell phone. Technological design is an iterative process that systematically applies heuristics in identifying and resolving tasks or problems with a creative, technology outcome. Designerly thinking describes a multidisciplinary way of knowing and reasoning that engages a variety of design approaches and criteria to create technological artifacts, solutions, and services.

Creativity and design praxiology. The technological capability component of creativity and design involves the practices that apply knowledge and skills (e.g., architectural, engineering, graphic, or industrial) in designing a creative resolution to a real-world task, issue, or problem. These practices serve as prerequisites to innovation (i.e., the production and marketing of the design). This capability employs active, iterative, and systematic engagement in the commonly accepted creativity praxiology of preparation, incubation, insight, evaluation, and elaboration. Identifying a new problem to focus on is a critical initial step in the creative design process. Designerly ways of higher order thinking (analysis and synthesis) and reasoning (inductive and deductive) are actively pursued in applying domain knowledge and heuristics in arriving at a novel response.

A few examples of creativity and design practices follow. First, brainstorming is a heuristic for generating diverse ideas. Producing visual mental imagery and physical models contribute to new insights and their refinement. Manipulating concrete materials in familiar contexts promotes synthetic thinking. Transferring knowledge from one context (e.g., super glue for materials) to solve a problem in a different context (e.g., superglue stitches for humans) enhances creativity. Lastly, focusing and persevering on a goal with intervals of diversion and rest are salient to achieving a creative outcome.

Applications of creativity and design in technology education. Technology teachers should exhibit empathy toward the creative needs of students and serve as guides and facilitators of creative endeavors. These teachers should plan, implement, and assess the knowledge and practices of creativity and design in technology education. Teachers and learners alike need to be appropriately motivated, persistent, and committed to achieve the advanced level of thought and doing for creative thinking, design, and problem solving. Taxonomies for cognitive, psychomotor, and affective domains can guide the development of goals, objectives, activities, and assessments. Instruction should enable the students to apply core and procedural knowledge to safely and properly design creative solutions and meet learning goals. Design challenges should be appropriate for the knowledge and skills of the learners. Opportunities for not only language-based thought, but also visual thinking through sketching, drawing, visualizing, modeling, and prototyping support creative design. The identification of steps for designing can serve as a basis for conceptual learning; however, the individual steps should serve as iterative heuristics for the students to achieve and not a linear formula for the design process. Project-based strategies provide synergy for creativity and design that enable authentic connections.

Students should be actively engaged in performance-based learning as they develop holistic perspectives. These learners should develop conceptual and procedural knowledge about design and technology. They should pursue active questioning, observing, networking, and experimenting as a basis for making connections of seemingly different ideas within various contexts. They should identify and define problems, research and investigate background information, establish criteria and constraints, generate ideas and design solutions, develop and apply mental and physical models, apply information and technology, analyze and evaluate potential ideas and solutions, and communicate and collaborate with their team members. Both convergent and divergent thinking and reasoning should be employed. Creativity and design strategies should be conducive to the learners' stages of human development and should be coherent through the P–12 grades. Interdisciplinary explicit knowledge and relationships of science, technology, engineering, and mathematics should be applied and transparent. Students also should have the opportunity to apply tacit representations of knowledge learned through their life and laboratory experiences. Design portfolios can assist both formative and summative assessment of the students' creativity through design.

The technology education classroom and laboratory environment should be physically, socially, and culturally established for creative design work. This environment should contain diverse contemporary information and material resources. Student motivation should be a result of intrinsic rewards for creativity and extrinsic rewards to focus on and meet design goals. Students should be guided by metacognition (reflecting on one's thought processes) in assisting them to be creative designers. An atmosphere of trust should prevail so that the students have the freedom to explore and adapt, take risks, make decisions, learn from failure, and be self-directed, yet collaborative learners.

PERSPECTIVES FOR ENHANCING CREATIVITY AND DESIGN IN TECHNOLOGY AND ENGINEERING EDUCATION

Examination of the preceding chapters and a review of selected literature on creativity and design has stimulated the author to propose the following actions for technology and engineering educators:

- Champion the benefits of engaging both linear left and spatial right brain thinking in designerly and other creative expressions.
- Adopt operational definitions for creativity and design in contributing to technological literacy and engineering literacy.
- Acknowledge the intrinsic value of creative expression, including design-based activities and competitive events in technology education.
- Differentiate key attributes, processes, and techniques for various types of technological design, especially engineering, architectural, industrial, and graphic.
- Understand, manage, and assess learner creativity during each developmental stage of P–12 learners.
- Endorse technology education as a key contributor to the human brain's development of conceptual knowledge, spatial reasoning, systematic processing, and divergent thinking that are required for creativity and technological design.
- Defend design as the core discipline for creativity, innovation, and design thinking within technology education.
- Assess design knowledge and skills as indicators of technological literacy and capability to creatively change our environment and advance our society and culture.
- Implement physical factors (i.e., lighting, color, furniture, resources, sensory variables, space configurations, and class sizes) that enhance creativity.
- Model such cultural environments as CHAD in Philadelphia for design education, educational reform, and socio-economic change.
- Develop the curriculum, implement the pedagogy, and assess learner knowledge and capability of creativity and design.

- Accentuate content, practices, and resources that promote and develop creativity and design during the professional development of preservice and inservice technology and engineering educators.
- Apply creativity and design in technology education to develop technologically literate and capable citizens, workers, and leaders who are then well prepared for full participation in the Conceptual Era of the 21st century.

CONCLUDING COMMENTS

Sternberg (2010) classified creativity as a habit that teachers can foster. "

> The main things that promote the habit are (1) opportunities to engage in it, (2) encouragement when people avail themselves of these opportunities, and (3) rewards when people respond to such encouragement and think and behave creatively. You need all three. (p. 394)

Design is an important body of knowledge and practices for manifesting creativity. Design is a dynamic medium for igniting creative sparks in learners to extend their potential and advance society by resolving technological challenges.

Both creativity and design are co-requisites for accomplishing human needs and desires in the Conceptual Age. Together this habit and the respective discipline will enable educated people to have meaningful, fulfilled, and prosperous lives. It is incumbent on technology and engineering educators to provide the leadership—valued in their beliefs, reflected in their discourse, and demonstrated through their actions—to instill the contributions of creativity and design that has been documented and promulgated throughout this 60th Yearbook of the Council on Technology & Engineering Teacher Education.

REFLECTIVE QUESTIONS

1. Should design as a component of technological literacy be reconstituted toward accomplishing the efficacy of engineering literacy? What is the rationale for your answer?
2. What three creative design strategies would you implement for your students to learn the tacit knowledge (know-how or procedural knowledge) needed for technological capability?
3. Why do employers rate "problem identification" as more important for their employees and school superintendents rate "problem solving" as more important for K-12 learners?
4. If P-12 schools and students were accountable for teaching and learning creativity, what knowledge and performance indicators should be developed and measured?
5. How should schools be transformed from the basic literacy model for the 20th century to a conceptual model for the 21st century?

REFERENCES

Amabile, T. M. (1983). *The social psychology of creativity.* New York: Springer-Verlag.

Amabile, T. M. (1996). *Creativity in context.* Boulder, CO: Westview Press.

American Management Association. (2010). *AMA 2010 critical skills survey—Executives say the 21st century requires more skilled workers* (Executive Summary). Retrieved from http://www.doc-txt.com/AMA-2010-Critical-Skills-Survey.pdf

Anderson, L. W. & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives* [PDF Document]. New York: Addison Wesley Longman. Retrieved from http://www.transitionmathproject.org/partners/wcp/doc/bloom.pdf

Apple, Inc. (2008, April). *Apple classroom of tomorrow—Today: Learning in the 21st century*. Retrieved from http://www.icyte.com/snapshots/show/70b7c398e25902e55cba86bbf9faebe5uuiduuid

Baer, J. & Garrett, T. (2010). Teaching for creativity in an era of content standards and accountability. In R. A. Beghetto & J. C. Kaufman

(Eds.), *Nurturing creativity in the classroom*, (pp. 6-23). New York: Cambridge University Press.

Cable, J. (2012, January 31). Corporate executives believe innovation and growth go hand-in-hand. *IndustryWeek.* Retrieved from http://www.industryweek.com/PrintArticle.aspx?ArticleID=26500

Committee on Conceptual Framework for the New K-12 Science Education Standards, National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: The National Academies Press.

Creativity. (1994-2010). In *Britannica Concise Encyclopedia*. Retrieved from http://www.answers.com/topic/creativity

Cross, N. (1982, October). Designerly ways of knowing. *Design Studies, 3*(4), 221-227.

Design. (n.d.). In *The American Heritage dictionary of the English language* (4th ed.). Retrieved from http://www.answers.com/topic/design

Dyer, J. H., Gregersen, H. B., & Christensen, C. M. (2009, December). The innovator's DNA [Reprint R0912E]. *Harvard Business Review*. Retrieved from http://www.epicentret.dk/hbr.pdf

Dyer, J., Gregersen, H. & Christensen, C. M. (2011, July 20). Five discovery skills that distinguish great innovators [Reprint by permission of Harvard Business Review Press. Excerpt from The Innovator's DNA.]. *Working Knowledge—The Thinking That Leads—Harvard Business School*, Research & Ideas. Retrieved from http://hbswk.hbs.edu/item/6760.html

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005, January). Engineering design thinking, teaching, and learning. *Journal of Engineering Education*, 103-120.

Florida, R. (2002). *The rise of the creative class and how it's transforming work, leisure, community and everyday life*. New York: Basic Books.

Florida, R. (2007). *The flight of the creative class—The new global competition for talent*. New York: HarperCollins Publishers.

Friedman, T. L. (2011, July 12). The start-up of you. *The New York Times*. Retrieved from http://www.nytimes.com/2011/07/13/opinion/13friedman.html

Frysh, P. (2011, August 31). West Virginia learns Finland's ' most honorable profession': Teacher. *CNN U.S*. Retrieved from http://www.cnn.com/2011/US/08/29/education.wv.finland/index.html?hpt=hp_bn1

Gemmill, P. R. (1989, March). Facilities—From unit shop to laboratory of technologies. *The Technology Teacher* (Special Commemorative 50th Anniversary Edition), 1-10.

Govindarajan, V. (2010, August 3). Innovation is not creativity. *Harvard Business Review*. Retrieved from http://blogs.hbr.org/govindarajan/2010/08/innovation-is-not-creativity.html

Hennessey, B. A. & Amabile, T. M. (2010). Creativity. *The Annual Review of Psychology*, *61*, 569-598. doi: 0.1146/annurev.psych.093008.100416

Herschbach, D. R. (1975). Use of the taxonomy of the psychomotor domain for the writing of performance objectives. *Journal of Industrial Teacher Education*, *12*(3), 48-56.

Huitt, W. (2007, October 26). *Success in the Conceptual Age: Another paradigm shift*. Paper delivered at the 32nd Annual Meeting of the Georgia Educational Research Association, Savannah, GA. Retrieved from http://www.edpsycinteractive.org/papers/conceptual-age.pdf

International Technology Education Association. (1996). *Technology for all Americans: A rationale and structure for the study of technology.* Reston, VA: Author. Retrieved from http://www.iteea.org/TAA/PDFs/Taa_RandS.pdf

International Technology Education Association. (2007). *Standards for technological literacy.* Reston, VA: Author. Retrieved from http://www.iteea.org/TAA/PDFs/xstnd.pdf

International Technology Education Association. (2009). *Technological design* (Second Edition). Retrieved from http://www.iteaconnect.org/EbD/Samples/HighSchool/TechDesign.htm

Kimbell, R. & Stables, K. (2008). *Researching design learning—Issues and findings from two decades of research and development.* Dordrecht, Netherlands: Springer Science + Business Media B.V.

Koenig, J. A. (2011). *Assessing 21st century skills—Summary of a workshop.* Washington, DC: The National Academies Press.

Krathwohl, D. R. (2002, Autumn). A revision of Bloom's taxonomy: An overview (pp. 212-218). *Theory into practice*, *41(*4), College of Education, The Ohio State University, Columbus, OH. Retrieved from www.unco.edu/cetl/sir/stating_outcome/documents/Krathwohl.pdf

Lawson, B. (1980). *How designers think: The design process demystified*. London: Architectural Press.

Levine, J. (2011, April 11). Finnishing school. *Time Magazine U.S.* Retrieved from http://www.time.com/time/magazine/article/0,9171,2062465,00.html

Lewis, T. (2007). Engineering education in schools. *International Journal of Engineering Education, 23*(5), 843-852.

Lichtenberg, J., Woock, C., & Wright, M. (2008, October). *Ready to innovate: Are educators and executives aligned on the creative readiness of the U.S. Workforce?* (Report No. R-1424-08-RR). New York: The Conference Board. Retrieved from www.artsusa.org/pdf/information.../ReadytoInnovateFull.pdf

Mayer, R. E. (2002, Autumn). Rote verses meaningful learning (pp. 226-232). *Theory Into Practice, 41*(4), College of Education, The Ohio State University, Columbus, OH. Retrieved from www.unco.edu/cetl/sir/stating_outcome/documents/Krathwohl.pdf

McAlister, B. K. & Krueger, A. J. (2000, July). *Technology Education Facility Planning: Frequently Asked Questions* [Project supported with grant from International Technology Education Association]. Department of Communication, Education, and Training, University of Wisconsin-Stout, Menomonie, WI.

Middleton, H. (2005). Creative thinking, values and design and technology education. *International Journal of Technology and Design Education*, *15*, 61-71.

Middleton, H. (2008). Examining design thinking. In H. Middleton (Ed.), *Researching technology education: Methods and materials* (pp. 193-212). Rotterdam, The Netherlands: Sense Publishers.

National Assessment Governing Board. (2010). *Technology and engineering literacy framework for the 2014 national assessment of educational progress*. Retrieved from http://www.nagb.org/publications/frameworks/prepub_naep_tel_framework_2014.pdf

National Governors Association. (2007a). *Innovation America a call to action: Why America must innovate.* Washington, DC: Author.

National Governors Association. (2007b). *Innovation America: Building a science, technology, engineering and math agenda.* Washington, DC: Author.

New Commission on the Skills of the American Workforce, National Center on Education and the Economy. (2007). *Tough choices or tough times.* San Francisco, CA: Jossey-Bass.

Osburn, B. N. (1948). *Constructive design*. Milwaukee, WI: Bruce.

Partnership for 21st Century Skills. (2008). *21st century skills, education & competitiveness—A resource and policy guide*. Tucson, AZ: Author.

Pink, D. H. (2006). *A whole new mind–Why right-brainers will rule the future.* New York: Riverhead Books.

Rose, M. (2004). *The mind at work—Valuing the intelligence of the American worker*. New York: Penguin Group.

Sawyer, R. K. (2006). *Explaining creativity: The science of human innovation.* New York: Oxford University Press.

Seemann, K. (2002). Constructivist vs behaviourist approaches in design computing education: Implications for the innovation economy. In H. Middleton, M. Pavlova, & D. Roebuck (Eds.), *Learning in Technology Education—Challenges for the 21st Century: Vol. 2* (pp. 174-181). Centre for Technology Education Research, Griffith University, Brisbane, Australia.

Seltzer, K. & Bentley, T. (1999). *Creative age: Knowledge and skills for the new economy*. London: Demos.

Simpson, E. J. (1972). The classification of educational objectives in the psychological domain. *The Psychological Domain* (pp. 43-56). Washington, DC: Gryphon House.

Spendlove, D. (2008). Creativity in education: A review. *Design and Technology Education: An International Journal, 10*(2), 9-18.

Sternberg, R. J. (2010). Teaching for creativity. In R. A. Beghetto & J. C. Kaufman (Eds.), *Nurturing creativity in the classroom*, (pp. 394-414). New York: Cambridge University Press.

The Conference Board, Corporate Voices for Working Families, Partnership for 21st Century Skills, & Society for Human Resource Management. (2006). *Are they really ready to work? Employers' perspectives on the basic knowledge and applied skills of new entrants to the 21st century U.S. workforce* (Research Report BED-06, 2006). Retrieved from http://www.p21.org/storage/documents/FINAL_REPORT_PDF09-29-06.pdf

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