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:
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- **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](http://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 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
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‘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


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.
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**Figure 3.** A Modern, Stackable Plastic Cup with Ergonomic Features Suitable for Casual Dining

![Modern Plastic Cup](image)

*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

![Fine China Teacup](image)

*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.
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](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*. 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


**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
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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
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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.

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 compositened 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
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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.
3 Additional information on the writings of Elizabeth B.-N. Sanders and convivial tools can be accessed at http://maketools.com

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