Int J Technol Des Educ (2009) 19:255–268
DOI 10.1007/s10798-008-9051-y

Creativity in technology education: providing children with glimpses of their inventive potential

Theodore Lewis

Published online: 5 February 2008

Abstract This article examines the claims of the school subject technology education (called Design and Technology in some countries) as a vehicle for inculcating creativity in the curriculum, by introducing children to the world of problem solving and invention. Core foundational underpinnings of the subject are explored, including its hands-on nature, its open-endedness, and its encouragement of generative cognitive processes. Issues relating to the teaching of problem solving are discussed. Examples of curricular approaches to the subject are set forth and their merits as bases for encouraging creative thinking are examined. Research on creativity in the subject is reflected upon briefly. The paper concludes by offering problem solving; and analogical, metaphorical, combination, and divergent thinking, as possible bases for pedagogy in technology education, and calls attention to the subject as a possible fruitful area of research based on creativity in the school curriculum.

Keywords Creativity · Inventiveness · Analogical thinking · Combination · Metaphorical thinking · Problem solving

Introduction

It is surprising that enhancement of creativity does not feature more prominently as a concern of schooling. The problem worsens now as global competition causes countries to stress the academic subjects more, using the results of standardized tests as the measure of student accomplishment and talent. The prized subjects such as mathematics and science tend to focus on convergent thinking, which is but one of the intellectual abilities (Guilford 1959). Subjects that are in the divergent thinking realm receive less attention in the schools. Such omissions in the curriculum mean that opportunities are thus missed to excite more students by helping them draw upon innate creative urges.

T. Lewis (✉)
Department of Work and Human Resource Education, University of Minnesota, 1954 Buford Avenue, St. Paul, MN 55108, USA
e-mail: lewis007@umn.edu

In an article in which he reviewed the results of studies on attempts to teach children to think creatively, Torrance (1972) reported confirmation of his own view that this was possible especially when the strategies allow "both cognitive and emotional functioning, provide adequate structure and motivation, and give opportunities for involvement, practice, and interaction with teachers and other children" p. 133. Guilford (1950) expressed the view that the development of creativity can be encouraged in schools but is inhibited by the conforming nature of schooling. While all subjects offer opportunities for the development of creative potential it can be argued that some offer better chances because they are not constricted by traditional academic norms. Aesthetic subjects such as art and music, along with technology education (or design & technology) are among those not so constricted. These subjects allow for the expression of multiple intelligences (Gardner 1993), because they broaden the range of domains within which talents can be uncovered.

This article focuses on the creativity prospects of *technology education* (term used especially the U.S.) or *design & technology* (U.K.). The subject makes claims as a context for encouraging creativity in children—claims that are examined here. When it was first introduced into the American curriculum in the 1870s as *manual training*, the subject drew heavily upon the industrial craft tradition, with its focus on tool-work, mechanical drawing, and material processing. Its primary advocate Calvin Woodward contended that because the subject engaged children with real objects and processes from the world about them, it thereby opened up aspects of their imagination not reached by the standard disciplines, with their emphasis on abstraction (see Woodward 1882). John Dewey was among important advocates who saw the importance of the subject for children, not so much as an interpreter of industry, but as a means of providing them with self knowledge of their own impulses, gained by seeing the external results of their motor activities. He wrote that:

> …the forms of occupation, constructive work, manual training (whatever name be given them), which are employed in the school, must be assigned a central position. They, more than any other one study, more than reading or geography, story-telling or myth, evoke and direct what is most fundamental and vital in the child; that in which he is heir of all the ages, and *through which he recapitulates the progress of the race* (Emphasis added). Dewey, p. 197.

Today, as reflected in *Standards for Technological Literacy* (International Technology Education Association 2000), and in Design & Technology curriculum provisions in the National Curriculum of the United Kingdom (Qualifications and Curriculum Authority 2001), the subject has been reconceptualized to reflect our technological world, with a strong focus on design, ranging over domains such as power and energy, construction, manufacturing, bio-technology, and communication technologies. The universally accepted aim is the inculcation of technological literacy. It may well be the case that tradition continues to exert its hold on classroom practice, but the forward direction of the field is in keeping with societal progress. Amid curriculum change, the basic potential of the subject to help students uncover talents not touched by other subjects remains an enduring goal. Increasingly the potential of the subject for stimulating creativity in children is being explored (e.g., Barlex 2007; Barlex and Trebell 2007; Christiaans and Venselaar 2005; Howard-Jones 2002; Liu 1998; Middleton 2005; Lewis 2005).

In the U.K. the new emphasis on creativity in the curriculum is traceable to recommendations from a report which called for it to be a consideration not just within the creative arts but in spheres such as business and technology (National Advisory Committee on Creative and Cultural Education 1999). This report argued against an elitist conception of creativity, calling instead for a "democratic definition" that fostered the creative potential of all, according to their particular strengths and abilities (p. 29). Thus creativity was set forth as "Imaginative activity fashioned so as to produce outcomes that are both original and of value" p. 30. This way of viewing creativity brings technology (and design) education squarely into the picture. It comports with the basic traditions and purposes of the subject globally, with imagining and making being core instructional aims.

There has been concern in the broader creativity discourse about fourth grade slump (the apparent decline of creativity in children between ages 9–10 and the onset of adolescence) and its possible causes (see Claxton et al. 2005), but little on whether there are curricular or instructional remedies. It is questionable whether such slump could have a developmental correlate. More plausible as reason might be conservatism in the curriculum, characterized by insufficient opportunity for open-ended pursuits that are joyful, that draw on endowments not otherwise tapped, and where teachers do not always have the answers.

In exploring the potential of technology education as a place in the curriculum where student creativity can be cultivated, this article is organized as follows (a) Focus on design, (b) Emergent classroom practice, (c) Emergent Research on children designing, (d) Inventiveness and the curriculum, (e) Coming to grips with creativity and invention, and (f) Conclusion.

Focus on design

Across the globe today there is convergence in technology education around topics such as problem solving, design, and construction techniques (Rasinen 2003). The subject has always had as its signature the conception and realization of artifacts. Now there is greater focus upon an intellectual processes approach through problem solving in which students puzzle over open-ended technological challenges. Resonating with the desirability of the new process approach, Middleton (2005) draws the attention of technology educators to the literature about the nature of the problem space and problem finding, pointing to creative correlates of cognition such as visual and mental images-generative tools that are associated with higher order thinking activity.

Long a feature of the U.K. version of the subject, *design* is gradually taking hold in the U.S. as the focus of technology education, informing several of the published content standards (see International Technology Education Association 2000). Design conceived as problem solving involves variations on an approach in which students are presented with an open ended problem that require them to ideate such that multiple possible solutions emerge. These solutions are evaluated and a product is realized based on the chosen solution strategy. More recently an *engineering design* approach has been taken (e.g., Wicklein 2006), conceived and taught less in terms of tacit knowledge and trial and error, and more in terms of analysis and prediction. This proposed shift is a source of tension for the field because it introduces a mathematics requirement which some believe may dampen the enthusiasm of children who are otherwise drawn to technology education because of its concreteness.

There is a very important debate in the technology education literature around the approach to teaching of design/problem solving. How much of this should be formulaic, and how much left to the devices of students? How much of it should be based on possession of content knowledge and on rational optimization methods? Wilson and Harris (2004) examined design and technology in U.K. schools, finding that the subject allows students opportunities to create what does not yet exist, and that by so doing it helps them improve their higher order thinking skills. But there is another side to this. Atkinson (2000) found that for the Design and Technology curriculum in the U.K. the steps in a prescribed linear problem-solving approach became units of assessment to which students were held accountable. She contended that these steps stifle the creativity of children. In her study of the relationship between the creativity of student projects and their overall performance on the GSCE (General Certificate of Secondary Education) examination she found that many students *who did not perform well on the exam* produced highly creative projects.

Also set in the U.K. McCormick (2004) identifies a similar issue. He contends that problem solving is taught *as ritual* where students are asked to produce a certain number of ideas. But classroom observations show that students subvert the curriculum by approaching problems in ways not anticipated by teachers. In similar vein, Mioduser and Kipperman (2002) contend that most curricular translations of problem solving are linear, with common rigid steps. Examining students at the stage of the problem solving process where they evaluate then modify chosen solutions, these researchers too found disparity between the standard problem solving model, and the way students went about it. Students did not learn in a linear way. It was found that many employed devices such mental models as aids to their learning.

Clearly this question of design pedagogy remains contested within the field. There is not consensus on the merits of teaching students a basic problem solving process as a prelude to their embarking on solutions to design problems. Indeed, there is some support within the engineering profession itself for the cautions raised with respect to the use of design algorithms in teaching. One general observation is that the solution of problems is dictated by the extent to which they are well or ill-defined (Newell and Simon 1972). Well defined problems may be solved algorithmically, but ill-defined ones require invented solutions. Hinrichs (1992) asserts that *constraints* may change during design, causing the engineer to switch the problem space, thereby opening up prospects for new solutions. Middendorf and Engelmann (1998) write that engineering design is iterative in nature, and that it depends upon the task at hand, the state of the art, or available resources. But even with this caution, they offer still the familiar basic problem-solving model.

Though design is viewed as the very essence of engineering, its place *in the curriculum that prepares engineers* is not settled (e.g., Court 1998; Dym et al. 2005). Thus it is not surprising then that design teaching in schools remains an area of contest. Heywood (2005) deals extensively with this issue, noting that part of the difficulty is that the theoretical basis of design is still not well grounded, and that it is difficult to assess student design efforts. Design does not take on the rigorous features of most of the engineering curriculum.

Still, those who frown on the use of design models as a pedagogic device must concede that models 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. In this vein Hong et al. (2006) report on observations made of the solution strategies of Taiwanese students during a robot bug contest, noting that a basic seven-step process was an aid to student creativity. They assert that the design process is more likely to be spiral than in nature.

Design models are used in industry by creativity-based enterprises. The IDEO Company that has emerged as one of the more innovative design firms in the U.S. employs a version of the basic design model used in schools (see Kelley 2001; Nussbaum 2004). There is the brain storming, and the creation and evaluation of prototypes. Likewise, Barak and Goffer (2002) provide an account of observations made of a company that used a design algorithm to good effect, the approach enhancing innovative productivity. This finding caused the authors to caution that there is need for some balance between completely open-ended approaches to problem-solving/design teaching in technology education, and approaches that are somewhat more bounded.

Emergent classroom practice

There is much to learn about the potential and capability of children if they are observed under conditions in which they can be inventive. Peterson (2002) has written that technology education classes and laboratories have potential for stimulating creativity, and recommends that students should be allowed to make mistakes and to learn from them; and that playfulness and humor should be tolerated. This is consistent with the findings of Amabile (1998) who identified challenge and freedom as factors supportive of the development of the intrinsic motivation needed for one to be creative.

In addition to the challenge inherent in designing and making projects, student competitions have become an important creativity stimulant. A popular type is the super-mileage competition that aims to see which vehicle designed and built by teams will be the most fuel efficient (e.g., Thompson and Fitzgerald 2006). Students build, test, and demonstrate the power of their designs by driving the vehicle under competitive conditions with constraints that are pre-specified. Another arena of student competition is robot design (e.g., Deal III 2001; Dillon 1995; Yu and Lin 2006) where students design and build robots that perform under constraints. Deal explains that the *beetlebot* contest requires the design of a robot that is capable of being controlled so as to transport a number of ping pong balls from the center of a ring to a goal. In support of this, students maintain technical notes that describe the problem solving process that yielded the robot. The notes must include sketches and any required mathematics. Robots are evaluated in terms of their design and operation, application of mathematics and science skills, the design journal, and how they fare versus the competition. Yu and Lin (2006) report on a robot competition in Taiwan that is the outcome of interdisciplinary course work. Students must invent a device that could accurately sort beads of two different sizes. They report that in the process, students in the competition generate hundreds of creative designs.

The technology education literature often includes design challenges that have a strong engineering flavor. For example Goel (2006) set forth a project where students are required to design, create, and realize a micro-fluidic device. Students are to work with rubber, cardboard, glue, tape and cylindrical pasta shells. Once they make the device, they must make presentations that include their own evaluation of how it might be improved. Bridge design has become a feature of technology teaching, even in elementary classrooms. Caroll (1997) described a bridge engineering project for elementary children, built from a truss kit. The activity was accompanied by a lecture and a slide show of famous bridges, the lecture including the introduction of concepts such as compression and tension. Also in the elementary school setting, Foster (2006) has proposed ways in which bridge building could be made more challenging, allowing for greater creativity. Students who have designed a bridge would evaluate it then redesign it in ways they believe to be more satisfactory.

As an engineering focus makes inroads in technology education classrooms, the conceptual phase of design may have to be followed by an analytic one that moves the process to predictive design. This line of thinking can be seen in Cotton (2002), who has proposed that mathematics be introduced into design teaching to help predict outcomes. Burghardt and Hacker (2004) have proposed *informed design* in which students design on the basis of prior knowledge and research, relying on mathematics and science to improve mathematics performance. They go about the normal design steps, but have a testing and redesign stage.

What many children cherish about technology education is the freedom it allows them to imagine and invent. Many students who are excited by developing robots, creating mousetrap-powered vehicles, or developing web-sites, are not thus challenged elsewhere in the curriculum. Howard-Jones (2002) has called attention to this, pointing out that generative thought processes are different from the analytical processes that are meant to refine them. He speaks of the dual nature of creativity in design, one stage involving generation of the idea, and that other involving evaluation. He argues that these two dimensions of creativity may not always come together in children. Those who have brilliant generative ideas may not have interest in the analytic phase, which requires closure.

Schools have to search harder to find ways to connect the enthusiasm that many students show in technology education classes with their performance in more purely academic subjects. It is possible that many students who are now thought to be poor academic performers might improve their achievement if the curriculum is made more applied. *Applied* here must not be construed to mean vocational. We may draw here upon situated cognition theory which suggests deliberate contextualizing of academic subjects against the backdrop of the more active subjects such as technology education (e.g., Brown et al. 1989; Lave and Wenger 1991; Sticht and Hickey 1991). Emergent classroom practices in technology education, such as have been described above, tend to connect the student with the real world of practice. The student sees that learning does not have to be sterile—that it can be practical, and yet thoughtful, requiring expenditure of inventiveness.

Emergent research on children designing

Though the research literature supportive of emergent classroom practice is fledgling, there is a growing body of reported studies that cast light on the challenge of teaching design and problem solving in technology education classes. One line of research examined elementary school children working with structures (Gustafson et al. 1999; Gustafson et al. 2000). In the first of these studies, the children were provided with a three-dimensional drawing of a cardboard tower that stood precariously, and were asked to indicate in writing how they would redesign it so it would not topple over. The children provided a range of suggestions, many of them quite insightful, including shortening, thickening, or bracing the supports; or widening its base. In the second of these studies (Gustafson et al. 2000) children were provided with illustrations of two bridges, and required to indicate which was stronger, and how they might test whether they are correct. The researchers got back many answers that they ordered into five categories. In the first they placed solutions where students described *why* one bridge was stronger than the other, but not *how* to test for bridge strength. In the remaining four the determining criterion was the students' scheme for testing. The researchers looked at the testing concept as well as its fairness, but for them the most successful children were those who imagined a fair test that allowed comparison of relative strength of the two bridges. This particular study was instructive in what it pointed out about the difficulties teachers might have in evaluating creative expression, including the problem of pre-conceptions they may hold as to where the creativity in children's work might reside. The researchers privileged the testing aspect of the challenge where some children devoted their energies to explaining why they thought one bridge to be stronger than the other. The following excerpt from the study points up the dilemma such students faced in the assessment of their work:

> Children in Category 1 could be viewed as having misread the question as they focused on describing *why* the bridge they circled was stronger than the other bridge rather than *how* to test for bridge strength. Some survey responses tended to focus on the *obvious differences* (Emphasis added) between bridge railing and children variously judged either slanted or vertical railings as key to structural strength (p. 12).

Truss configuration is a key to bridge strength, triangles being an integral aspect of some types of designs. Thus children were bringing observational knowledge to bear on their conclusions about what made one bridge stronger, thinking like engineers by paying attention to the configuration of railings, a dimension of the challenge that the researchers down-played. The researchers were looking elsewhere for creativity.

Druin and Fast (2002) reported on a study in which a group of Swedish children ages 5 and 7 collaborated with researchers to create new story telling technologies. The researchers were of the view that invention supports children's learning. Children in the study invented ways of telling and depicting stories. In the course of the project, they kept journals which were then analyzed by the researchers. The analysis unearthed several constructs that characterized identities the children assumed as they became engaged in the learning activities of the study.

In a study that examined the infusion of thinking skills into a design course (in mechatronics), Doppelt (2007) reports that students learned how to document their design process via portfolios, in the process displaying high levels of creative thinking skills. Engineering tasks that were part of the curriculum pursued by students included the design and building of a prototype. An interesting aspect of the approach to teaching here was that students did not have to follow a prescribed design method; rather, they were allowed to modify a basic design process as they saw fit. Also reporting research in which students' creativity came to the fore, Webster et al. (2006) observed the teaching of design where the children were asked to invent a small recycling device suitable for a home garden. They kept a journal that was a record of their drawings and ideas. Students were allowed a period of incubation to crystallize their design ideas. One finding was that content knowledge made a difference. Students with broad knowledge of recycling produced more creative devices.

The emerging research on children's generative thinking in technology education provides a great boost to a field that traditionally has been short of focused inquiry. These studies will in time tell us more about the inventive potential of the subject—its ability to provide a vehicle through which students can draw on their creative urges. We are beginning to understand how children think when posed with technological challenges. This kind of work can add a distinct increment to what is known about the capabilities of children.

Inventiveness and the curriculum

There has been lament in the educational literature that *invention* as a specific kind of creative endeavor is rarely addressed directly in the school curriculum. We see this concern in McCormack (1984), Plucker and Gorman (1999), and Shlesinger (1982). McCormack (1984) described ways in which invention could be taught based on workshops he had conducted with children, teaching them to think outside of the box by reinventing old inventions, and engaging them in hands-on and stimulating activities such as designing their own kinds of kitchen appliances, and building better mousetraps. Plucker and Gorman (1999) found that children who were exposed to inventive opportunities came away enjoying hands-on activities and group work. Shlesinger (1982) described his own efforts at teaching children in an inventive mode, and encouraging them to invent with great success, their efforts yielding useful inventions. It is clear from the sparse mainstream educational literature on inventiveness in the schools, that the efforts within technology education are not well known outside the field. More needs to be done across countries to make educational policy makers and researchers more aware of this aspect of the subject. Invention and design are correlated.

What do we know about inventiveness that can be drawn upon in technology (and design) education curricula? Using the work of inventors of the telephone (Alexander Graham Bell, Thomas Edison and Elisha Gray) as exhibits, Carlson and Gorman (1992) contend that inventors draw upon three types of cognitive strategies when they go about their work, inclusive of *mental models*, *mechanical representations*, and *heuristics*. Mental models are constructions that can be animated in the mind of the inventor. Mechanical representations link thought with devices. Inventors have a set of stock solutions that are part of their cognitive resources. Heuristics are strategies including rules of thumb that inventors use to manipulate models and representations.

Looking at the invention of the airplane, Crouch (1992) contends that the Wright Brothers possessed the genius of *visualizing the abstract*. They could envision how forces might operate in the machine they had in mind. They also engaged in *analogical thinking*, the bicycle with its requirement of constant tradeoff between stability and control being the perfect model for simulating the technical challenge of flight. Dasgupta (1996) asserts that "technological creativity," which has to do with original invention and design, "is an intellectual, cognitive act." p. 180. The creative technologist is armed with a body of dynamically changing knowledge, including general mental problem solving tools, heuristics, and means-ends analysis. This knowledge might also include disciplinary content such as math and science. Knowledge facilitates design, which involves mental actions that "transform symbolic representations of physical or abstract things into other symbolic representations…." p. 181. Representations of goals, such as artifacts, are in the minds of the technologist and can be externalized into sketches, equations or drawings. Dasgupta then arrives at a conceptual framework based upon case histories of invention, in which there is focus on ideation. The framework suggests that the act of inventing is (a) *purposive* (goal oriented), (b) *opportunistic* (relying on sub-goals), (c) *gradualistic*—large insights being composed of a network of small steps, (d) a reasoning processes involving application of rules, (e) knowledge intensive (science, theory heuristics, and (f) involves searching freely and associatively for knowledge.

These characterizations of the nature of inventing are useful in the extent that they underscore the kinds of cognition along with elements of creativity that are drawn upon by inventors. For inventing to become a stronger feature of technology education, it will be necessary for teachers of the subject to become more fully grounded in the ways of inventors—their modes of thought, cognitive strategies, and the kinds of knowledge upon which they draw.

Coming to grips with creativity and invention

What then are the creative prospects of technology education as a school subject? What kinds of creative processes seem reasonably to be associated with its teaching? What pedagogic strategies seem likely to stimulate the inventive urges of children? There is evidence from the literature that technology education is a place where a host of generative cognitive processes are more likely to occur as a part of learning process than elsewhere in the curriculum. Such processes include *problem solving*, *divergent thinking*, *combination*, *metaphorical thinking*, and *analogical thinking*. These processes must be understood by the technology education community so they could inform pedagogy intending to aid students in arriving at more creative solutions when then become engaged in acts of inventing in the classroom. Each is reflected upon briefly next.

Problem solving

As indicated earlier in this article, problem solving has been a staple of technology education teaching though the role of problem solving models as design pedagogy is still an unsettled area. In his seminal work on problem solving Duncker (1945) wrote that a problem arises when there is a goal that cannot easily be reached. The resolve to reach the goal leads to thinking. Problems are not solved in a single step. Rather, the principle or functional value of the solution emerges, followed by the final form of the solution, which develops as the principle becomes more concrete. Thus there are a set of mediating phases along the way in solving a problem, some of which could be errors from which one can learn. At each stage, there is reformulation of the problem, which means the solver has essentially arrived at a new problem. Thus the essence of problem solving is to reformulate the problem more productively. Dunker also addressed the issue of *functional fixedness*, a hindrance to problem solving, as prior knowledge about the typical function of an object prevents one from conceiving of its use atypically.

In his triarchic model of intelligence, Sternberg (1985) dealt with problem solving as a manifestation of intelligence. The process involves decomposition into *metacomponents* of intelligence, such as problem solving, selection of a solution strategy, allocation of mental and other resources (such as time) to the problem, solution monitoring, and sensitivity to feedback (p. 99).

Pretz et al. (2003) point out that from a research point of view the early stages of problem solving are much less understood than late stages. Little is known about what causes some people to seek out ill-defined problems and to devise ways to represent them. Included among needed areas of research interest is the question of functional fixedness. They wondered whether there are ways to help children break out of comfortable or known mental sets so they could see new possibilities when solving problems. Students may indeed assume a 'design stance' in technology education classrooms, where knowledge of how things work prevent consideration of new possibilities. On this point, Defeyter and German (2003) found that 5-year-old children were more likely to use a tool for an atypical purpose after being primed about its baseline purpose, than were 6- and 7-year-old children, because the latter were captive to their knowledge of the *intended purpose* of the tool.

Divergent thinking

Divergent thinking requires a mindset that more than one solution to a puzzle is possible (Baer 1993). Guilford (1967) set forth 16 divergent production factors that could be divided into four categories, namely *fluency* (ability to produce a number of ideas), *originality* (ability to produce unusual ideas), *flexibility* (production of a variety of ideas), and *elaboration* (ability to embellish ideas). These provide a useful frame for the conduct of divergent thinking studies. For example, utilizing the Guilford categories, Charles and Runco (2000–2001) found some evidence of a developmental influence on the appropriateness of ideas. Divergent thinking can be seen as an important dimension of problem solving in technology education classrooms at the ideation stage, where it is desirable to be open minded about possible solutions.

Combination thinking

Combination involves merging two ideas or concepts into a third such that the resulting synthesis is autonomous and of utility in its own right (see Scott et al. 2005; Welling 2007). It is felt that people who are creatively inclined have greater associative propensities than those less so, and are able to arrive at combinations through remote associations. A jazz pianist may incorporate classical playing into a composition. In the search for cures for affliction, researchers may explore combinations of drugs. An engineer may find it necessary to marry electrical and mechanical systems. In the technology education classroom, much creativity could come from having students make remote associations in their quest for solutions to problems.

Metaphorical thinking

Problem solving and design in technology education may be aided if children are encouraged to employ the use of metaphors as an aspect of their thinking. Metaphorical thinking allows one to make conceptual leaps across domains from a source to a target, such that a new situation can be characterized and understood by reference to a familiar one (Glucksberg and Keysar 1990; Glucksberg et al. 1997; Lakoff 1993). Glucksberg and Keysar (1990) contended that metaphors are class-inclusion statements that assume hierarchy. We see this in the popular characterization that the internet is like an information highway. The lucrative benefit package afforded a CEO upon dismissal is referred to as a golden parachute. Parachutes and highways are exemplars of particular classes, the one as a prototypic safe landing mechanism, the other as a facilitator of traffic. Metaphors indeed make possible connections among unlike entities, through principles of association (e.g., Gentner and Jeziorski 1993). This quality makes them particularly important in representation of ideas in science and technology. Miller (1996) writes of the creative power of metaphors—on the extent to which they help us bring realism to the problem space. In particular he identifies two types, one based on *substitution* or *comparison* (e.g., person x is a giant) and the other on interaction ("x acts as if it were y)" (p. 114). Miller contends that the first type is weak because both the primary and secondary subjects are known entities. In the second, the interaction type, the metaphor is in tension, heightening the possibility of creativity. He cites several examples of the use of interaction metaphors by great scientists. Metaphorical thinking can be an aid to design pedagogy, if technology education teachers can first demonstrate their use in class, and then encourage children to arrive at their own. For given problem solving exercises, teachers may use metaphorical prompts to try to push students toward solution.

Analogical thinking

Analogies are special types of metaphors, where a structural feature from a base domain is mapped onto a new domain (Dreistadt 1969; Gentner et al. 1997; Gick and Holyoak 1980).

Analogies make possible the solution of a problem in the target domain by superimposing upon it a solution from the base domain. For example, a spider's web can stimulate the solution to an architectural problem. Water flow can help explain current flow. Gick and Holyoak (1980) found that it was possible to solve a problem in one domain via use of an analogical problem from another domain.

Analogical models do not turn on literal comparisons only. All features of the base domain do not have to map onto that of the new domain. In setting forth observations of this order Gentner (1983) offered structure-mapping theory, in which there is selective mapping of features in the analogy. Thus, to say that an electric battery is like a reservoir is to say that this is so only because they both share storage capacity (relational structure), other shared features being irrelevant. By this method of selectiveness relational structures that apply in particular domains can apply in others. Analogies are able by structure mapping to cause conceptual change. Structure mapping asserts that analogical thinking requires a process of alignment between two mental representations such that the structural match between them is maximized (Gentner and Markman 1997). The contention is that analogical thinking via structural mapping can project candidate inferences from the base to the target. Kolodner (1997) suggests that analogical thinking can be made more of a part of education, if children can be called upon to engage in solving real world problems, including projects that meet community needs. This kind of entreaty is entirely in keeping with the aims and practices of technology education.

Conclusion

This article has examined the claims of technology education as a means by which children can develop their creative potential, through design and inventive activities. It is evident that the subject provides a variety of avenues by which children can employ cognitive resources not ordinarily taxed by the academic curriculum. Design and problem solving activities challenge children and teachers alike. Teachers must decide how much to rely on models that spell out stages in design/problem solving.

The article reviewed theory relating to problem solving, analogical and metaphorical thinking, divergent thinking, and combination thinking, processes that can be integrated into instructional methods employed by teachers in ways that can facilitate the development of creativity and inventiveness in children.

Whether the claims made about the creativity dimension of technology education are well founded can ultimately be tested only via programs of research. The great potential of the subject as a place where inventiveness can be inculcated is being realized by national governments (notably the U.K., where it has been compulsory K-12), and by engineering bodies. Still, this subject is a virtually unexplored area of creativity research that has great potential for engaging interdisciplinary teams of researchers. It is hoped that this article raises attention enough about its possibilities as fertile ground for understanding inventive dimensions of children.

References

Amabile, T. M. (1998). How to kill creativity. *Harvard Business Review, 76*(5), 77–87.

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*, 255–281.

Baer, J. (1993). *Creativity and divergent thinking*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, Publishers.
Barak, M., & Goffer, N. (2002). Fostering systematic innovative thinking and problem solving: Lessons education can learn from industry. *International Journal of Technology and Design Education, 12*, 227–247.
Barlex, D. (2007). Creativity in school design & technology in England: A discussion of the influences. *International Journal of Technology and Design Education, 17*(2), 149–162.
Barlex, D. M., & Trebell, D. (2007). Design-without-make: Challenging the conventional approach to teaching and learning in a design and technology classroom. *International Journal of Technology and Design Education*, Published Online, February 28, 2007.
Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.
Burghardt, M. D., & Hacker, M. (2004). Informed design. A contemporary approach to design pedagogy as the core process in technology. *The Technology Teacher, 64*(1), 6–8.
Carlson, M. B., & Gorman, M. E. (1992). A cognitive framework to understand technological creativity: Bell, Edison, and the Telephone. In R. J. Weber & D. N. Perkins (Eds.), *Inventive minds: Creativity in technology* (pp. 48–79). New York: Oxford University Press.
Caroll, D. R. (1997). Bridge engineering for the elementary grades. *Journal of Engineering Education, 86*(3), 221–226.
Charles, R. E., & Runco, M. A. (2000–2001). Developmental trends in the evaluative and divergent thinking of children. *Creativity Research Journal, 13*(3&4), 417–437.
Christiaans, H., & Venselaar, K. (2005). Creativity in design engineering and the role of knowledge: Modeling the expert. *International Journal of Technology and Design Education, 15*, 217–236.
Claxton, A. F., Pannells, T. C., & Rhoads, P. A. (2005). Developmental trends in the creativity of school age children. *Creativity Research Journal, 17*(4), 327–335.
Cotton, S. E. (2002). Making problem-solving simulations more realistic. *The Technology Teacher, 62*(3), 29–32.
Court, A. W. (1998). Improving creativity in engineering design education. *European Journal of Education, 23*(2), 141–154.
Crouch, T. D. (1992). Why Wilbur and Orville? Some thoughts on the Wright Brothers and the process of invention. In R. J. Weber & D. N. Perkins (Eds.), *Inventive minds: Creativity in technology* (pp. 80–92). New York: Oxford University Press.
Dasgupta, S. (1996). *Technology and creativity*. New York: Oxford University Press.
Deal, W.F., III (2001). The great robot beetle challenge. *The Technology Teacher, 60*(8), 17–20.
Defeyter, M. A., & German, T. P. (2003). Acquiring an understanding of design: Evidence from children's insight problem solving. *Cognition, 89*, 133–155.
Dewey, J. (1901). The place of manual training in the elementary course of study. *Manual Training Magazine, 11*(4), 193–199.
Dillon, R. (1995). Using a robotics contest to enhance student creativity and problem solving skills. *The Technology Teacher, 55*(1), 11–14.
Doppelt, Y. (2007). Assessing creative thinking in design-based learning. *International Journal of Technology and Design Education*. DOI: 10.1007/s10798-006-9008-y .
Dreistadt, R. (1969). The use of analogies and incubation in obtaining insights in creative problem solving. *Journal of Psychology, 71*, 159–175.
Druin, A., & Fast, C. (2002). The child as learner, critic, inventor, and technology design painter: An analysis of three years of Swedish Student Journals. *International Journal of Technology and Design Education, 12*, 189–213.
Duncker, K. (1945). On problem solving. *Psychological Monographs*, 28(5), Whole Number 270.
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.
Foster, P. N. (2006). Reengineering activities in K-8 classrooms: Focus on formative feedback. *The Technology Teacher, 65*(7), 20–24.
Gardner, H. (1993). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.
Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155–170.
Gentner, D., Brem, S., Ferguson, R., Wolff, P., Markman, A. B., & Forbus, K. (1997). Analogy and creativity in the works of Johannes Kepler. In T. Ward, S. Smith, & J. Vaid (Eds.), *Creative thought* (pp. 403–459). Washington, DC: American Psychological Association.
Gentner, D., & Jeziorski, M. (1993). The shift from metaphor to analogy in Western Science. In A. Ortony (Ed.), *Metaphor and thought* (pp. 447–480). Cambridge: Cambridge University Press.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist, 52*(1), 45–56.
Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306–355.
Glucksberg, S., & Keysar, B. (1990). Understanding metaphorical comparisons: Beyond similarity. *Psychological Review, 97*(1), 3–18.
Glucksberg, S., Manfredi, D. A., & McGlone, M. S. (1997). Metaphor comprehension: How metaphors create new categories. In T. B. Ward, S. N. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 327–350). Washington, DC: American Psychological Association.
Goel, L. (2006). Engineering a microfluidic device. *The Technology Teacher, 66*(2), 7–8.
Guilford, J. P. (1950). Creativity. *The American Psychologist, 5*(9), 444–454.
Guilford, J. P. (1959). The three faces of intellect. *The American Psychologist, 14*(8), 469–479.
Guilford, J. P. (1967). *The measure of human intelligence*. New York: McGraw-Hill.
Gustafson, B. J., Rowell, P. M., & Guilbert, S. M. (2000). Elementary children's awareness of strategies for testing structural strength: A three year study. *Journal of Technology Education, 11*(2), 5–22.
Gustafson, B. J., Rowell, P. M., & Rose, D. P. (1999). Elementary children's conceptions of structural stability: A three year study. *Journal of Technology education, 11*(1), 27–44.
Heywood, J. (2005). *Engineering design: Research and development in curriculum and instruction*. New Jersey: John Wiley and Sons.
Hinrichs, T. R. (1992). *Problem solving in open worlds: A case study in design*. Hillsdale, NJ: L. Erlbaum Associates.
Hong, J.-C., Tseng, H.-Y., & Chang, H.-Y. (2006). A study of the creative thinking process of robot combat contest: A case study of robot bug contest. In *International Conference on Technology Education in the Asia Pacific Region Conference 2006 Proceedings* (pp. 120–127). Hong Kong Polytechnic Institute: Hong Kong Technology Education Association.
Howard-Jones, P. A. (2002). A dual-state model of creative cognition for supporting strategies that foster creativity in the classroom. *International Journal of Technology and Design Education, 12*, 215–226.
International Technology Education Association. (2000). *Standards for technological literacy—content for the study of technology*. Reston, VA: Author.
Kelley, T. (2001). *The art of innovation*. New York: Doubleday.
Kolodner, J. L. (1997). Educational implications of analogy. A view from case based reasoning. *American Psychologist, 52*(1), 57–66.
Lakoff, G. (1993). The contemporary theory of metaphor. In A. Ortony (Ed.), *Metaphor and thought* (pp. 202–252). Cambridge: Cambridge University Press.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
Lewis, T. (2005). Creativity: A framework for the design/problem solving discourse in technology education. *Journal of Technology Education, 17*(1), 36–53.
Liu, Y.-T. (1998). Personal versus cultural cognitive models of design creativity. *International Journal of Technology and Design Education, 8*, 185–195.
McCormack, A. J. (1984). Teaching inventiveness. *Childhood Education, 60*(4), 249–255.
McCormick, R. (2004). Issues of learning and knowledge in technology education. *International Journal of technology and Design Education, 14*, 21–44.
Middendorf, W. H., & Englemann, R. H. (1998). *Design of devices and systems*. New York: Marcel Dekker Inc.
Middleton, H. (2005). Creative thinking values and design and technology education. *International Journal of Technology Education, 15*, 61–71.
Miller, A. I. (1996). Metaphors in creative scientific thought. *Creativity Research Journal, 9*(2&3), 113–130.
Mioduser, D., & Kipperman, D. (2002). Evaluation? Modification cycles in junior high students' technological problem solving. *International Journal of Technology and Design Education, 12*, 123–138.
National Advisory Committee on Creative, Cultural Education. (1999). *All our futures: Creativity, culture and education*. London: Department for Education and Employment (DfEE).
Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood cliffs, CA: Prentice-Hall Inc.
Nussbaum, B. (2004). The power of design. *Business Week Online*, May 17, 2004. Retrieved from http://www.businessweek.com/magazine/content/04_20/b3883001_mz001.htm
Peterson, R. E. (2002). Establishing the creative environment in technology education. *The Technology Technology, 61*(4), 7–10.
Plucker, J. A., & Gorman, M. E. (1999). Invention is in the mind of the adolescent: Effects of a summer course one year later. *Creativity Research Journal, 12*(2), 141–150.

Pretz, J. E., Naples, A. J., & Sternberg, R. J. (2003). Recognizing, defining, and representing problems. In J. E. Davidson & R. J. Sternberg (Eds.), *The psychology of problem solving* (pp. 3–30). Cambridge, UK: Cambridge University Press.

Qualifications and Curriculum Authority. (2001). *Design and technology*. UK: Department for Education and Skills. Retrieved from see http://www.ncaction.org.uk/subjects/design/index.htm

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

Scott, G. M., Lonergan, D. C., & Mumford, M. D. (2005). Conceptual combination: Alternative knowledge structures, alternative heuristics. *Creativity Research Journal, 17*(1), 79–98.

Shlesinger, B. E., Jr. (1982). An untapped resource of inventors: Gifted and talented children. *The Elementary School Journal, 82*(3), 214–220.

Sternberg, R. J. (1985). *Beyond IQ: A triachic theory of human intelligence*. New York: Cambridge University Press.

Sticht, T. G., & Hickey, D. T. (1991). Functional context theory, literacy, and electronics training. In R. F. Dillon & J. W. Pellegrino (Eds.), *Instruction: Theoretical and applied perspectives* (pp. 82–106). New York: Praeger.

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

Torrance, E. P. (1972). Can we teach children to think creatively. *The Journal of Creative Behavior, 6*(2), 114–143.

Webster, A., Campbell, C., & Jane, B. (2006). Enhancing the creative process for learning in primary technology education. *International Journal of Technology and Design Education*. doi: 10.1007/s10798-005-5633-0.

Welling, H. (2007). Four mental operations in creative cognition: The importance of abstraction. *Creativity Research Journal, 19*(2–3), 163–177.

Wicklein, R. C. (2006). Five reasons for engineering design as the focus for technology education. *Technology Teacher, 65*(7), 25–29.

Wilson, V., & Harris, M., (2004). Creative change? A review of the impact of design and technology in schools in England. *Journal of Technology Education, 15*(2), 46–65.

Woodward, C. M. (1882). The function of an American training School. *The Journal of Proceedings and Addresses*, National Educational Association, Session of the Year of 1882.

Yu, K.-C., & Lin, K.-Y. (2006). Implementation of design and making, interdisciplinary integration, and creativity in technology education curriculum. In *International Conference on Technology Education in the Asia Pacific Region Conference 2006 Proceedings* (pp. 74–82). Hong Kong Polytechnic Institute: Hong Kong Technology Education Association.