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Creative Thinking, Values and Design and Technology Education

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ABSTRACT: The development of Design and Technology curricula has always been premised on the importance of the act of designing and of the value of the contingent activity of creative thinking. Despite this, there has been a great deal of uncertainty about methods for developing creative thinking abilities in design and technology students. However, the results of research from cognitive psychology, engineering and invention suggest some promising strategies for application in design and technology classes. Moreover, these strategies are emerging during a time when issues concerning ethics and values are also being raised. This paper presents a brief summary of the research into problem-solving and design. It then explores a range of creative thinking strategies, and of their possible applications in design, and goes on to argue that the strategies and settings that promote creative thinking in design and technology make the area not only one that is suitable for addressing ethics and values, but that it may be one of the major reasons for including design and technology programs in school curricula.

Keywords: creativity, design and technology, engineering, invention, psychology, research, values

INTRODUCTION

Design and technology programs have been seen by practitioners and administrators to perform various roles in school programs. On the one hand the area has been regarded as requiring low-level intellectual skills and as a suitable vehicle for developing physical skills in manipulating concrete materials. On the other hand, claims have been made that because students regard design and technology learning activities as challenging, and 'real', that the activities that take place in these settings involves more profound learning. However, until recently, there was little evidence to support either proposition. In this paper I will draw initially on cognitive research into designing and problem-solving to support the argument that designing is a complex intellectual activity. Then I will draw on material from the literature on mental imagery, engineering and invention to suggest that we now have sufficient research to draw some conclusions about the nature of designing and of learning in design and technology. Finally, I will draw on recent research on values to suggest an important purpose for design and technology education.

Designing

Designing, has, until comparatively recently, been seen as a largely unproblematic process within the psychological literature that includes it as a

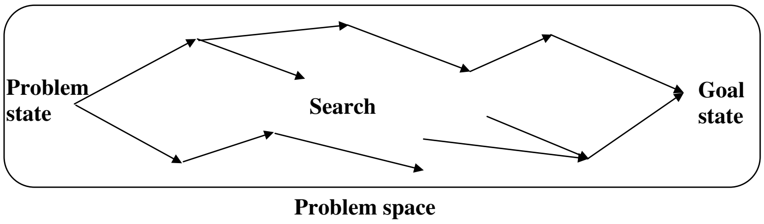

Figure 1. Model of a problem space (Newell & Simon 1972)

category of problem solving (Greeno & Simon 1988). Problem-solving has been characterised in terms of the problem space model shown in Figure 1. In the problem space model, problems are regarded as occurring in a *problem space* that contains three elements. The first element is what is described as the *problem state*. This consists of all that is known of the problem at the start of problem-solving. For example, the inability to cross a river, the need to get to the other side, the width and depth of the river etc. might constitute the problem state of a problem that has a bridge as one solution. The second element is the *goal state*. The goal state is intended to represent the solution to the problem, and in the case above is the bridge, but might be a tunnel. The third element is the *search space*. The search space is taken to be all of the information the problem-solver has in their memory or can access from books, the Internet etc. that will help them solve the problem. In the river problem, the search space might include knowledge of bridges, construction methods, appropriate materials etc. Problem-solving is sometimes characterised as a journey with the 'space' constituting the territory the problem-solver 'navigates' to reach the goal state (Newell & Simon 1972).

The implication contained in the problem space model is that each of the steps in designing can be accomplished in the same way that a mathematical problem might be solved if you know the steps. This view has been supported from cognitive psychology (Anderson 1993; Greeno et al. 1988; Simon 1981), with information processing theory arguing for a similar process for solving simple or complex problems. Indeed, the same model, illustrated in Figure 1, has been used to characterise the nature of all problem types and of the way people solve them.

When designing is described in terms of the process to use in design and technology programs in schools, the process is often represented in a diagram that generally includes the steps of: identifying a problem, undertaking research, generating plans of solutions, producing solutions, and evaluating the solutions. There are many variations of the diagram, with Johnsey (1995) identifying 17 different versions in schooling in England and Wales between 1970 and 1995. However, all are essentially variations of the process listed above. In terms of the problem-solving literature, the process is still seen as unproblematic and able to be characterised using the problem space model.

The Newell and Simon (1972) problem space conceptualisation does work for simple problems and problems where it is possible to specify all aspects of the problem space. Indeed, the model assumes that there is a specific and singular starting point and that there is one precise and correct solution. It also assumes that all strategies required to solve the problem will be present in the search space and need only be found by a process of search, in the same way that a motorist might find the route to a particular destination. As with a journey by car, there may be a number of different routes to be taken, but they are all regarded as capable of being found by a process of search. Design problems, however, tend not to have precise starting or finishing points (Goel 1988; Goel & Pirolli 1992; Schon 1990) and they are generally solved by a combination of strategies that come from memory and existing, available knowledge, and strategies that have to be created.

In characterising design problems in terms of the problem space model above, it can be argued that the problem state is generally ill-defined and opaque. Ill-defined because the customer for the design and the designer do not generally have a clear idea of the dimensions of the problems, and some may not be apparent at the start of designing. In solving the design problem, there may be many possible paths to follow to achieve a solution and there may be complex and contradictory relations between particular paths. For example, to design a chair that is strong but light presents this contradictory relationship, which Schon (1990) describes as figurally complex. That is, if you change one aspect (strength) it will probably have an effect on the other (weight). Schon argues also, that the information processing explanation of problem-solving, derived from the problem space model, is unable to explain the fact that the processes involved in solving design problems, and indeed, possible solutions, often emerge during the course of designing. Table I provides a summary of the characteristics of design problems in terms of the problem space model.

As a response to the inadequacies of the Newell and Simon (1972) model, Middleton (1998, Unpublished thesis) developed and examined a modified Version of Newell et al.'s problem space model. The model is illustrated in Figure 2.

Table I
Summary of characteristics of the problem space of design problems (Middleton 1998)

Problem state	Search and space	Goal state
Ill-defined	Numerous procedures	Ill-defined
Opaque	Figurally complex	Figurally complex
	Opaque	Contradictory criteria
	Emergent procedures	Emergent criteria
	Constructed procedures	Creative

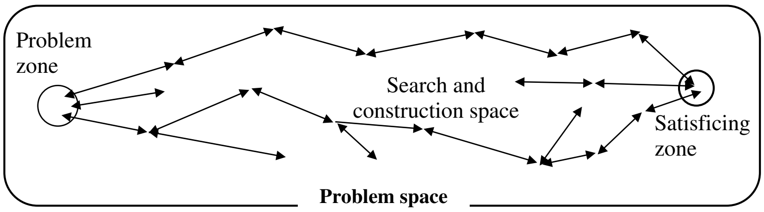

Figure 2. Revised concept of a problem space (Middleton 1998).

The modifications were made to account for the particular characteristics of design problems. The modified model does make the point that design problems are complex and ill-defined and that there is a need to use creative strategies, hence, the addition of the term construction, in the search and construction space. The model has been used in studies of architectural design (Middleton 2004), high school design and technology classes (Middleton 1998, Unpublished thesis), and complex problem-solving situations in tourism (Middleton 1996) and the airline industry (Middleton 1997).

The next section explores research in psychology and invention in terms of the findings about creative and inventive thinking and the implications of the findings for design and technology teaching. However, it is necessary to frame the exploration with some observations about the changing status of different ways (representations) of knowing, and the impact of the changing status on current thinking about creativity and design.

Representations of knowledge

The act of designing involves the use of at least three representations of knowledge. The three representations are visual, verbal and tacit. That is, designing involves: producing and using mental images that are in some way isomorphic to objects in reality; producing and using abstract propositions of knowledge that can be likened (broadly) to verbal renditions of knowledge, such as in descriptions of processes; and using tacit knowledge, which may be derived from either of the two previous representations or from perception of physical action. Of these three, visual and tacit representations appear to be central to the process of creative thinking in terms of the research in psychology and invention.

The idea that visual or tacit representations of knowledge might be important to the generation of ideas is relatively new and, even now, not uncontested. It has been a common view that ideas were only seen to have importance if and when they could be expressed in words. Indeed, the Australian radio commentator, Phillip Adams, expressed the view that ideas do not really exist until they have been rendered in words. More generally, ideas expressed in images or concrete representations were seen as not so important, and ideas expressed in ways that are neither verbal nor visual, such as tacit knowledge, were seen as least important. Thus there was seen to be a hierarchy of representations of knowledge with abstractness seen as most cognitively demanding and most important. This is played out in education where universities, which are seen to deal with abstract, verbally mediated ideas are seen to be more important than technical colleges, which deal more with visual and concrete ideas, and these are seen as more important than settings where tacit knowledge is gained through practice of a skill, such as a workshop setting. (Fortunately, this generalisation is becoming less general.)

However, work in cognitive psychology (e.g., Anderson 1982) suggests that when the mind processes procedural knowledge, or the knowledge of how to do something, it uses the same mechanisms to processes thoughts as it does to process physical actions. That is, there is no higher-order mechanism for processing abstract thoughts that is separate from one used for concrete thought, using, for example, imagery, or physical action.

It also used to be thought that only abstract representations of knowledge were used in complex thinking. However, we now know that humans use mental imagery to solve complex problems (Kaufmann 1990), and moreover, that images can provide the most efficient representations for solving complex problems. Larkin and Simon (1987) have provided some useful evidence to suggest why this is so. Larkin and Simon argue that images provide more efficient representations for problem-solving because the material in an image is organised according to the relations of the problem content rather than being organised according to the rules that apply to the abstract code. That is, a written description of an object is organised according to the rules of grammar. This means that any part of an object that is located adjacent to on another physically, may be described in writing by sections of text that are quite separate within the overall description. In images and sketches, parts that interact with one another, are located next to each other. One only needs to think about describing a pulley system to someone who has never seen one using either words or diagrams, to see the utility of the latter. However, designing is a particular form of problem-solving where it is possible to both explain some of the processes by which successful designing occurs, and to draw on these processes to suggest strategies design and technology teachers may employ to assist their students' creative thinking.

Images and creativity

Designing involves the devising of solutions to problems where there is the requirement that, in addition to solving the problem, the solution be creative. That is, that the solution be original and purposeful (Torrance 1964). Work by Finke (1989), Finke and Slayton (1988) and Finke et al. (1992) have provided some important findings that suggest that the use of visual mental images provides a powerful representation for generating creative solutions to design problems. In one large research project Finke and Slayton (1988) demonstrated that with suitable instructions, students could use visual mental images to respond to design-like problems. In solving the problems, they generating solutions, a significant number of which, were judged to be noticeably creative. In another project Finke et al. (1995) demonstrated that people could use imagery to produce more creative responses to design like problems if, in addition to combining shapes to produce something new, they were required to create the constituent parts, using mental imagery.

Weber (1992), Weber et al. (1990) and Weber and Perkins (1989) examined the way contemporary inventors in engineering produce new solutions to problems. Weber et al. found that inventors routinely use visual mental images to both represent possible inventions, and to vary parameters and to test the effects of the variations. For example, in the study published in 1990, Weber et al examined the way a contemporary inventor used mental visual images when inventing a sub-soil herbicide spreader. The inventor reported being able to visualise the spreader in operation, including the details of the spray nozzles and their location. In addition, the inventor was able to visualise varying the spacing and diameter of the spray nozzles, and to be able to visualise the effect the variations had on the operation of the device. Thus, Weber et al. found that inventors used both static and dynamic visual mental images in the generation and testing of new solutions to engineering problems.

Tacit knowledge and invention

Carlson and Gorman (1992) examined the invention processes of a range of famous inventors such as Bell and Edison. Carlson and Gorman found that in addition to visual mental images, inventors worked from existing objects to create new ones. By working from, Carlson and Gorman meant that they had the physical items available to view, handle and use as idea starting points. Thus, viewing and manipulating objects that had some meaningful relationship to the to-be-invented object was seen as important to the process of invention. However, no explanation for the role these objects, or their handling has on the inventive process has been provided. It is assumed that the objects and their handling constitute a form of tacit knowledge that is used in the inventive process to stimulate new ideas. We don't yet understand the role of tacit knowledge in the generation of new ideas other than to note that inventors report it consistently as a part of the invention process.

In summary, designing, inventing, and the related activity of design and technology learning are: complex activities requiring higher-order thinking; where that higher-order thinking is facilitated not primarily by abstract thought but by visual mental imagery and the manipulation of concrete materials; in situations and contexts that are meaningful to the designer.

VALUES

The findings above are useful in terms of the implications they might have for the process of designing and of learning in design and technology education. Equally important, however, are the purposes that might be served by learning in design and technology. In June 2002 the Thinking Conference was held in Harrogate, England. The Keynote speakers, among others, included David Perkins, Robert Sternberg and Howard Gardner – three of the leading researchers in thinking, creativity and intelligence. However, Perkins presentation departed from his previous themes of inventive thinking and was concerned with morality, Sternberg's paper went beyond his previous work on intelligence to explore the issue of wisdom, while Gardner concluded that performing what he called "good works" which he describes as "when excellence and ethics meet" (Gardner et al. 2001) is important. In other words, all three presenters had come to the not particularly surprising conclusion that intelligence and creativity were not of themselves enough, and that human thought and action, even very clever thought and action, needed to be mediated by what is variously referred to as ethics or values or something connoting 'goodness'.

This information might be interesting and indeed compelling in its apparent logic and contemporary relevance, given current and recent past world events such as the war in Iraq and 9/11. However, it still begs the question of how this relates to design and technology education, and indeed how it relates to what is argued in the earlier part of this paper. The connection lies in the nature of the activities students engage in within the design and technology classroom.

Meaningfulness and good works

A key feature of any good design and technology classroom is that the activities that students engage in are meaningful. They are meaningful because they have a contingent relationship with the real world that is both inside and outside of the classroom. That is, the ideas and processes that students engage with are connected to the lived world rather than being abstracted from it. They are connected to the real world both inside and outside the classroom because they may engage in solving design problems for home, for others, or for the school. Furthermore, the solutions students' produce are real solutions from real materials.

We are also working with children where values are an inescapable if not always overt part of the learning activities. When we set students particular human problems to solve we present them with choices: choices about the kinds of materials and processes to use; the kinds of artefact they produce, whether their proposed solution involves hazardous processes, or will have features that might be dangerous for the user of the product. Design and technology students also work within institutional and social values. For example, many educational authorities forbid the construction of weapons or other dangerous items.

Many of these values are implied, by teachers when they set design problems, and by students when they respond to design briefs. However, whether values are implied or are an overt part of the process of solving a design problem they are an inescapable part of the process. This makes the design and technology classroom a particularly appropriate setting for addressing questions of value, or what Gardner et al. (2003) call 'good works'.

The significance of the research work referred to, and the argument presented above is not simply that we can insert some 'values' learning into the design and technology curriculum. Rather, the important point to be argued here is that design and technology is meaningful to students. This meaningfulness is related to the ways in which knowledge is represented in design and technology, which is a function of the settings, and tasks students engage with. Moreover, because one cannot design without values, the task for the design and technology teacher is to make the values an explicit part of the design task. In examining how this might be done values are examined in terms of the modified problem space model presenter earlier.

The modified problem space model is useful in terms of representing values as a dimension of designing. It can be argued that value judgements are a necessary component of each of the three stages of the modified problem space model. In the problem zone the most salient value judgement to be made is whether the problem as presented is worth solving. There are plenty of produces on the market to suggest that this question needs to be asked more often. (For example, the problem of roads being too crowded with cars is a design problem that is usually solved with freeways, but might more appropriately be posed as a problem of insufficient transport for people, that may be solved by improved public transport.) In a school setting the value aspect of the problem zone can be expressed through the nature of design briefs that are selected. For example, design tasks that focus on energy efficiency or the design of alternative energy devices would provide opportunities for addressing values.

Within the satisficing zone, questions of value arise in terms of the impact of the product as conceived, in terms of the environment, safety or society, to name a few (For example, the use of endangered rainforest timbers for design products). The issue of energy consumption of a particular house design is a value question that resides within the satisficing zone. Indeed, the use of the term satisficing zone acknowledges the issue of value in any design solution. That is, the term satisficing zone is used in the model to acknowledge that the act of designing does not result in a correct solution, but rather, one that is the best that can be achieved with the limits of imagination, materials and processes that are available at a particular time. The determination that a solution satisfies requirements, is thus a value judgement.

Within the search and construction space, designers and students are devising processes for achieving a satisficing solution. In doing so, values are a component of the process. Values can be economic, environmental, safety, etc. For example, will a proposed process make the solution too expensive, produce too much pollution in terms of dust and fumes, or require the designer/student to undertake a construction task that is potentially unsafe.

It is not difficult to see how value is a component of the design problem space and that values apply to designing at both the professional and school level. Values, as a component of professional design may be implicit and based on the professional designers knowledge. In design and technology classrooms, where knowledge about values is as important as the fact of their incorporation in student designs, values needs to be an explicit of the design process. As noted earlier, the design process provides a natural setting for considerations of value.

As a consequence of this, design and technology is best placed to have students explore questions of value. In such a proposition, the object of the design and technology learning experience is not simply to have students learn how to come up with bigger, faster or cheaper gizmos, but to have students design with values as a key component of the designing and the learning that comes from the activity.

CONCLUSION

In this paper the existing research literature has been used to argue that designing is a complex intellectual activity that requires higher-order thinking. It is also argued that this thinking is best facilitated by non-abstract representations of knowledge such as visual mental images and concrete representations, rather than the abstract representations previously thought of as those used exclusively for complex thinking. The argument was then presented that because of the kind of learning environment that occurs in good design and technology settings, which use the representations of knowledge referred to earlier, and tasks that are meaningful for students, these setting are appropriate for exploring questions of value. In drawing this conclusion I will draw on Herbert Simon's 1981 book *The Science of the Artificial*, where he argued that all human activity could be divided into two categories. The first he called the natural sciences, and defined them as being concerned with understanding 'the way things are'. The second he regarded as design and called it the science of the artificial, and defined it as being concerned with understanding 'how things might be' thus Simon saw the normative aspect of design as a fundamental and defining characteristic.

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