Exploring the Interrelationship of Problem Solving and Design in Hard Materials Technology

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Abstract

An understanding of the nature of the relationship between problem solving and design is central to successful technological outcomes in technology education. Research has identified this relationship as ill-defined, expressed simplistically and under researched (Mawson, 2001; McCormick, 2004; Williams, 2000) particularly with respect to working with, and learning about hard materials technology (Kelley, 2008). This paper reports on the ways in which expert technologists, in the domain of mechanical engineering, and expert technology teachers have conceptualised the relationship between design and problem solving in the context of hard materials. Five expert technologists and an equivalent group of technology teachers were interviewed about this relationship in order to provide data to characterise an essential element of learning to design and problem solve in the context of hard materials. That is, a key essential element of learning to design and problem solve in the context of hard materials includes recognising the interrelationships between design and problem solving. This information can be linked to curriculum reform and implementation.

Keywords: *interrelationship design and problem solving, expert technologists, hard materials technology teachers, mechanical engineering*

Introduction

Over the last two decades, an emphasis on the two areas of design and problem solving has been identified as a key factor that has helped to distinguish the subject of technology as a separate curriculum area in education (Mioduser & Dagan, 2007; Stein, Docherty, & Hannam, 2003). A major justification for including design and problem solving in technology curricula is that these have been acknowledged as essential elements of what expert technologists do in their everyday work (Cajas, 2002). However, there remains some confusion regarding what can be defined as problem solving and what can be defined as design. Very often the two terms have been used simultaneously or interchangeably with little recognition of any distinctive meaning (Mawson, 2001; McCormick, 1997).

Consequently, although the terms design and problem solving are banded together and used interchangeably, the interrelationship between the terms is unclear and difficult to establish. This author considers it important to find out the interrelationship of design and problem solving in order to unwrap in what ways this might be presented more clearly to students in technology classrooms. As design and problem solving are very often associated with hard materials, it was decided to centre this investigation within this context.

Background

In a review undertaken in the United Kingdom, Johnsey (1995, 1998) found little distinction between the described design and the problem-solving processes. Johnsey acknowledged that most of these 17 design and/or problem-solving models fitted a four-stepped linear outline, which he summarised as investigation, invention, implementation and evaluation. It is evident that Johnsey's design and problem-solving outline has significant parallels with the general problem-solving models of Dewey (1933) and Polya (1957) that were used for science and mathematics. From an international perspective, these stepped design and problem-solving processes have been summed up in various ways that reflect the interchangeable use of the terms design and problem solving but not the interrelationship of the two terms. For example in Australia, "design-make-appraise" (Australian Education Council, 1994) was the preferred construct of technological design and problem solving (Mawson, 2001). In the United States, it is described as the technological process or method that is: define problem; generate ideas; model; test (International Technology Education Association, 2000; Savage & Sterry, 1990), reflecting a greater emphasis on the problem-solving component. In England and Wales, there is a stronger emphasis on the design component in technology and this was expressed initially as: identify; generate design; plan and make; evaluate (DES/WO, 1990).

While there have been attempts to describe an interrelationship between design and problem solving in technology education, there seems to be confusion regarding the place of problem solving in design or, design in problem solving. In technology education literature and technology curricula, the interface of design and problem solving has been expressed in many different ways. Because design is often described as a process employed to provide a solution to an overarching problem posed, design is considered a process within technological problem solving (Taylor, 2000). However, there are many situations where design creates an artefact because someone has perceived a need or opportunity recognising that design often occurs where there is no overarching problem to solve (McCormick & Davidson, 1996). McCormick, Murphy, and Hennessy (1994) express an interrelationship in the early technology curriculum in England and Wales as design being the “manifestation” of a problem-solving process (p. 5). Stein et al. (2003) define design in technology education as a form of problem solving, while Middleton (2005) considers design as a defining component of technological problem-solving. The Australian technology document, Technology for Australian Schools (1994) describes the interrelationship as “the problem-solving based design process” (Middleton, 2009).

In engineering, design has been expressed as a “special form” of problem-solving (Mital, Desai, Subramanian, & Mital, 2010, p. 28). That is, even when design tasks develop from an unfulfilled need or opportunity, these tasks can be manipulated into a problem from which a design develops. Vincenti (1991) identified an engineering design being able to deconstruct a problem into smaller problems to provide detail such as production processes, types of materials, sizes and clearances.

In addition, the literature also identifies a tension concerning the interrelationship of design and problem-solving. For example, Barak and Goffer (2002) recognise a major challenge in technology education is design based on openness and disorder, on the one hand, and employing systematic methods for innovative thinking and problem solving, on the other. Hill and Anning (2001) have characterised this tension as a requirement to use the “divergent traditions of art and design” (p. 118) to develop creative solutions to problems while, at the same time, requiring a functioning product that has employed the “convergent traditions of technology” (p. 118). Mioduser and Dagan (2007) discuss this conflict in terms of design having to be creative and “branching” using multi-disciplinary knowledge yet, at the same time, having to meet the requirements of production processes when creating solutions to problems. In other words, design is constrained by problem solving required to address the practicalities to manifest the design into an outcome.

In summary, design and problem solving are often sandwiched together with little distinction made between them. At the same time, there are disparate views of the interrelationship between design and problem solving in technology education and an engineering design and problem-solving context. In addition, a tension has been identified relating to the interrelationship between design and problem solving in technology education.

In this research project, five expert technologists who design and problem solve using hard materials and five secondary hard materials technology teachers were asked how they consider design and problem solving and in what ways these two aspects interrelate in the context of hard materials. Therefore, the first research question guiding this research is: **In what ways do expert technologists conceptualise the relationship between design and problem solving in the context of hard materials?** The second research question is: **What are technology**

teachers' conceptions of design and the role of problem solving in hard materials technology?

The ten participants for this research were selected using purposive sampling as it enabled two groups of participants to be chosen because they were "knowledgeable people" who had "in-depth" understanding about specific issues (Cohen, Manion, & Morrison, 2007). Both groups of participants have developed and constructed their knowledge through beginning and ongoing participation in Communities of Practice (CsoP) that have their own distinctive cultures and histories (Lave & Wenger, 1991). The expert technologists belong to technological CsoP and the technology teachers belong to educational CsoP. Four of the teacher participants also belonged to technological CsoP prior to becoming teachers.

In this research, the two different research participant groups (experts and teachers) were required to meet two different sets of criteria. Because mechanical engineering provides a broad area of design and problem-solving expertise in the context of hard materials, it was chosen as the domain from which to select the expert technologists. The five experts were recruited from three distinctive groups within this domain: New Zealand Certificate in Engineering (NZCE) or diploma-level qualified engineers; certified trade-qualified engineers; and professional mechanical design or product engineers. The purposive sampling criteria for technology teachers required the teachers to be teaching a current hard materials technology programme that involved students Year 10 (14–15 year olds) or above so they had experience of students likely to be involved in design and problem-solving activities with hard materials.

Method

This research used an interpretivist mode of inquiry because it enabled expert technologists' and technology teachers' understanding of concepts, knowledge and interpretations about their understanding and learning to inform the research (Cohen et al., 2007). Therefore the researcher was able to build a detailed picture of the ways in which experts and teachers consider design and problem solving interrelate in the context of hard materials. Data collected using an interpretivist mode of inquiry is filtered through the interpretivist eyes of the researcher when analysed and presented as findings (Merriam, 1998). In selecting data and illustrative quotations to include in this research paper, every endeavour was made to ensure these represented what was intended by the participants (Cohen et al., 2007).

While the theoretical perspective in this research is interpetivism, the procedural foundation or ontology is social constructionism (Sarantakos, 2005). As a result, the 10 research participants were able to share their subjective interpretation of their knowledge and understanding acquired as a result of their interaction with the world (Sarantakos, 2005).

The data collection technique used was individual face-to-face semi-structured interviews with the experts and the teachers (Bryman, 2004). This technique was chosen as semi-structured interviews have the advantage of being flexible enough to enable each interviewee to respond in their own unique way to the guide questions and to contribute rich detail in their own words (Brenner, 2006).

During the early stage of the analysis, coding was used to classify and identify key pieces or segments of text (Creswell, 2008). At this coding stage, tags were allocated to particular pieces of text interpreted as relevant to the two research questions (Neuman, 2003) and later classified further into major ideas (Creswell, 2008). Memoing was used in the analysis process alongside the coding process to develop and identify concepts from the text (Punch, 2005). During the memoing process, the researcher's own perspectives and worldview; the information identified in the literature review; and reflection on the research questions are brought together (Merriam, 1998). In this research, once the coding and memoing were completed, identification began of the key findings that could be linked to the two research questions.

Findings

The expert technologists' and the technology teachers' analysed data provide a rich and broadened explanation of the interrelationship of design and problem solving in the context of hard materials. First the experts' findings are presented followed by those of the teachers.

Expert Technologists

An overall finding from the expert technologists' analysed data is that, in the context of mechanical engineering, problem solving is interrelated strongly with design. Six key findings are presented below to indicate the ways in which these experts conceptualise this interrelationship of problem solving with design.

First - is that an initial problem defines a need for design. While this is not the sole reason for design, the technologists identified it as significant. This conception of design reflects the first step of the problem-solving and design processes as presented in much of the early technology education literature which commences with defining a problem and continues with devising (design) solutions to solve the problem (Savage & Sterry, 1990). Although these technologists did not focus solely on this problem-solving aspect, they stated that solving an overarching problem often constituted the reason to design, described by John (Expert Technologist [ET], 3) as: “the problem has to be known up front before you could design around it”.

The second finding focused on this interrelationship where designing is often turned into what James (ET, 2) described as a “big problem” before the design begins. Mital et al. (2010) likewise identify, in engineering design, even an overall “unfulfilled need” initiating a design, can often be formulated into a problem. In other words, the process of design may be manipulated and viewed as a “big” problem which is solved by developing a design as a solution regardless of whether or not it is solving an overarching problem or meeting a need or opportunity (McCormick & Davidson, 1996).

The third key finding identified that when realising a complex design, there are further problems (identified in this research as subsidiary problems). These problems include but are not necessarily manufacturing-type problems. However, they may require further design solutions to enable the overall design or solution to the “big problem” to function. These experts emphasised that for a design concept in engineering to “practically work”, there is a myriad of subsidiary problems that also must be solved. James (ET, 2) explained this as “a problem within a problem”. He said to solve the subsidiary problems, “you drill down through the overall problem into all the detail”. In support of this view, George (ET, 1) also stated that, in real estate, it's “location, location, location” but in engineering design with hard materials it's “detail, detail, detail”. In other words, the design must incorporate the detail to accommodate the subsidiary problems encountered as part of the overall design. Therefore George (ET, 1) identified that design cannot be “separated at all” from problem solving which was supported by Brian (ET, 4) who stated that he could not separate design from problem solving “in the line of work we do”. Likewise, James (ET, 2) also identified design in engineering as “problem solving one way or another”. The experts' views reflect those of Vincenti (1991) who identifies the need for engineering design to address all the practical considerations of manufacturing, material choice, and the need to deconstruct a large problem into smaller problems.

A fourth finding, which relates to the previous concept of solving subsidiary problems as a design develops and providing detail within a design - is the conflict of a design providing extensive technical detail while striving to be innovative. In other words, the interrelationship of design and problem solving can create a tension between innovation and practicalities which includes the cost-effectiveness of the design. This concept of design and problem solving mirrors literature acknowledging the tension between technological design as conceptual and innovative (Barak & Goffer, 2002) at the same time as systematic and functioning (Hill & Anning, 2001) and addressing the constraints around being able to be produced and manufactured (Mioduser & Dagan, 2007). George (ET, 1) described this tension as: "If you're going to provide an innovative design to get to the practical stage you've got to solve all the problems ... innovative and imaginative they're the easiest bits. It has to be practical and able to be built at a realistic cost".

A fifth finding showed that the technologists recognised that many subsidiary problems associated with engineering design do not require solving by means of a design solution. However, these types of subsidiary problems have to be addressed in the processing and manufacture of designs and therefore are still a key component of, and interrelate with design where an outcome is a product. As Peter (ET, 5) commented a designer must think: "how can we build it and then looking at smart ways of doing it ... you've got to have that practical side". Vincenti (1991) also identified the need to consider production processes when designing to produce a realised outcome.

A sixth key finding is that design is a problem-solving process that optimises constraints and trade-offs to find the best possible solution. While problem solving with hard materials may not always be associated with design, the experts considered that design cannot stand alone, without the inclusion of problem solving.

> I see almost all design is problem solving one way or another. I think problem solving is the right term for optimising something ... if you make it better you've got a better solution to that problem you're trying to solve. ... Not all problem solving is design, almost all design is problem solving as I see it so I have a hard time separating design and problem solving. ... Design is a process but it's a problem-solving process (James, ET, 2).

The experts' conceptualisations of the interrelationship of design and problem solving reflect the view of McCormick et al. (1994) that design is the "manifestation" of the problem-solving process (p. 5). That is, that the design encompasses the thinking, knowledge ideas and problem solving to create an outcome. Likewise, the experts' views also reflect the position of Middleton (2005) that design is seen often as a defining component of technological problem solving.

Technology teachers

The findings of the five hard materials technology teachers' conceptions of the interrelationship of design and problem solving indicate several similarities to those of the expert designers and problem solvers. First, teachers described design in some situations solving an overarching problem in a specific technological context (Savage & Sterry, 1990).

Second, like the experts, the teachers considered *subsidiary* problem solving an integral part of designing with hard materials and acknowledged that designing requires being able to solve practical-type *subsidiary* problems as a design is realised. As Patrick (Technology Teacher [TT], 5) notes: "concepts of design, but in terms of hard materials it has to work and it has to be processed and it has to be functioning". Henry (TT, 4) described this as: "you learn to be a designer by problem solving ... a familiarity with processes through problem solving". This view identifies with McCormick (2004) who points to manufacturing-type problems occurring frequently in technology classrooms however this receives little recognition in curriculum documents. Likewise, these teachers' views reflect Stein et al. (2003) who identify design in technology education as a form of problem solving. However, in contrast to the technologists' views, the teachers' views emphasise the processing and manufacturing-type of subsidiary problems not necessarily the subsidiary problem solving as a component of developing a design concept.

Third, teachers recognised optimisation as a factor in design and problem solving with hard materials. As Henry (TT, 4) identified: "we look at … whether or not we've got the facilities to actually manufacture that solution to that problem, whether it's going to cost too much, take too much time, take too much expertise". The expert technologists also acknowledged the necessity of developing an optimum design incorporating the many different design constraints. These sentiments reflect those of Mioduser and Dagan, 2007 concerning the constraints on designed artefacts of being able to be manufactured and produced.

The last aspect of the interrelationship of design and problem solving identified designing including problem solving. This aspect echoes that of the experts who recognised design as a problem-solving process. Andrew (TT, 1) described this as: "everything that's been designed has had some sort of problem solving prior to it".

It is summarised further by Matthew as:

> I see design and problem solving as one and the same thing really... when you're designing something you're problem solving but at a higher level. … Probably design is the ultimate problem solving (Matthew, TT, 3).

Both Matthew's and Andrew's views and those of the experts reflect *the Technology for Australian Schools* (1994) document describing the interrelationship as "the problem-solving based design process" (Middleton, 2009).

The technology teachers' conceptions of the integration of design and the role of problem solving may be summarised as: design solving an overarching problem; design requiring components of practical subsidiary problem solving as a design is realised; design including optimisation which must consider constraints when solving a problem; and design as a problem-solving process. To conclude from the technology teachers' data, it would appear that subsidiary problem solving receives less emphasis in terms of how it is integrated within the whole design process when compared to the technologists' data.

From the technologists' findings, problem solving is not just defined as an overarching problem that is solved by a design solution or solving the practical subsidiary manufacturing-type problems. Instead, design is described as a problem-solving process that requires ongoing solving of subsidiary problems within the design to provide the detail that produces a realised functioning outcome, including solving the subsidiary practical manufacturing-type problems. While the teachers acknowledged design as a problem-solving process, and recognised the manufacturing-type subsidiary problems as relevant to design, they did not specify addressing the detail required in design as ongoing subsidiary problem solving.

Discussion

This research has identified from the findings of the experts' and teachers' data the interrelationships between, design and problem solving as important in supporting the learning of design and problem solving in technology education. A key overarching element from this research characterising an interrelationship of design and problem solve is the role of subsidiary problem solving as an integral component contributing to the complex nature of design with hard materials. This interrelationship of design and problem solving includes but extends beyond the notion of design solving an overarching problem posed. Instead, it identifies a myriad of subsidiary problems, nested and sequential. For example, the conception of the interrelationship of design and subsidiary problem solving includes predicting, addressing and solving the many subsidiary problems within a design so that the design detail can be mapped out appropriately to enable the production of a final realised functioning product or system in-situ. Subsidiary problem solving recognises the design detail that takes into account an awareness of tolerances, the selection and processing of materials and, issues relating to mechanisms. This subsidiary problem solving also includes predicting and addressing the practical problems that may arise in the manufacture of a design and installation in-situ.

This research also has recognised design with hard materials requiring a balance between innovation and imagination and subsidiary problem solving that deals with the constraints, technicalities and practicalities of producing a realised functioning outcome.

Implications

A key implication from this research is the necessity for technology teachers to identify clearly the integral nature of subsidiary problem solving within design. It appears that technology education in the context of hard materials does not acknowledge or identify specifically the integral role of problem solving within design, including the tension between design as innovative and the constraints of subsidiary problem solving as it relates to addressing the practicalities, and detail of the design.

Students also need to understand this construct of subsidiary problem solving in design to be able to understand more clearly the requirements and complex nature of design in the context of hard materials.

Conclusion

The purpose of this research was to explore the interrelationship between design and problem solving in the context of hard materials so it could be made more explicit for teachers and students in technology education. The interrelationship was explored from the perspectives of expert technologists and technology teachers. In the context of hard materials, the findings indicate that design is a problem-solving process and that subsidiary problem solving is an integral part of design. While design always strives to be innovative and creative, it must address the subsidiary problems that arise within the design including the practicalities of manufacturing and producing the design. In further research, it may be interesting to find out the types of experiences in the context of hard materials to support students learning to design including the integral component of subsidiary problem solving within design identified in this research.

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