The effect of problem type on the strategies used by novice designers

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Abstract

Previous research by the author demonstrated that untutored Year 7 students produce a solution to a design-and-make task in ways significantly different to those prescribed by textbooks. However, the strategy used may have been a function of the particular design brief and how it was presented. The follow-up study described here addressed the question: Is the design strategy used by novices dependent on the task?

Four Year 7 dyads were video recorded while designing and making a solution to a specific task. Comparisons were made between dyads in the current study, between each dyad and a map of the theoretical model, and between dyads in both studies.

Analysis showed no significant difference between dyads in the current study, nor between dyads in the two studies, but confirmed significant differences between dyads' strategies and those described in the literature. Students did not use two-dimensional modelling to explore and communicate a design proposal, nor did they generate multiple solutions. They moved immediately to three-dimensional modelling, but often lacked the requisite skills to develop their ideas. While students used the design process skills identified in theoretical models their strategy was less linear and more iterative.

Introduction

Previous research by the author demonstrated that untutored Year 7 students produce a solution to a design-and-make task in ways significantly different to that prescribed by textbooks. They (a) make greater use of three-dimensional modelling than suggested by textbooks; (b) sequence the sub-processes of designing quite differently to the prescribed models; and (c) do not generate several possible solutions from which to select the one they judge to offer the most promise as an effective solution, but develop ideas serially. However, it is possible that the strategy used may have been a function of the particular design brief and the way in which it was presented.

The follow-up study described here addressed the question: Is the design strategy used by novices dependent on the task? Additionally, the study provided the opportunity to further investigate protocol analysis as a methodology for the analysis of novice designers' strategies and to refine a coding scheme to describe design process skills.

This paper begins with a description of the theoretical framework used for the study and a review of related literature. Next, the method used to collect and analyze data is described. This is followed by discussion of the strategies used by students in this study, how these compare to results from previous research, and how the strategies used by students in both studies differ from those in theoretical models of the design process. The implications of these findings for the teaching of design and technology complete the paper.

The centrality of designing

Much current school work presents tasks to students in a form that assumes there is only one correct way to do it and often only one correct solution. Design and technology education, however, presents tasks that have many possible solutions. Furthermore, it provides students with opportunities to apply knowledge, to generate and construct meaning. It fosters the kind of cognition that combines declarative knowledge, the *what*, with procedural knowledge, the *how*. As

Kimbell, Stables, Wheeler, Wosniak and Kelly (1991) point out

> "there [is] general agreement on certain basic tenets of [technology education]. It is an active study, involving the purposeful pursuit of a task to some form of resolution that results in improvement (for someone) in the made world" (p. 17).

And as Breckon (1995) reiterates "technology [education] provides that excellent method of learning - learning through doing" (p. 11).

The "doing" in technology education involves using design process skills to design and make an artifact in response to a need. A typical form of design process includes: identifying needs and opportunities, understanding and detailing the problem, generating possible solutions, building a solution, and evaluating a solution. This process shares many properties with a general problem-solving model used in the resolution of ill-structured problems (Simon, 1973).

According to Jones (1970)

> "all [models of the design process] are attempts to make public the hitherto private thinking of designers, to externalize the design process" (p. 3).

This is nearly always accomplished by using a diagram to show the steps in the process and the relationships between them. Siraj-Blatchford (1993) notes that

> "providing a simplified model of the process of design which teachers may adopt heuristically provides for the student what Bruner (1986) has termed scaffolding" (p. 22).

Models of the design process are readily available in both the technology education literature and school textbooks, and a number of authors have provided detailed historical accounts of their development (e.g., Johnsey, 1995a; Welch, 1996). A recent model

> "reject[s] the idea of describing the [design] activity in terms of the products that result from it, and instead concentrate[s] on the thinking and decision-making processes that result in these products" (Kimbell et al., 1991, p. 20).

The essence of this model is that ideas conceived in the mind need to be expressed in concrete form before they can be examined to see how useful they are. In other words,

> "the inter-relationship between modelling ideas in the mind and modelling ideas in reality is the cornerstone of capability in ... technology" (Kimbell et al., p. 21).

Yet as Johnsey (1995a) suggests "the model is ... (purposely) vague about what might be happening at any point in the process" (p. 207), reminding us of Lawson's (1990) observation that, in attempting to describe how designers design, "there is not a great deal of action to be seen ... it is what goes on in the designer's mind which really matters" (p. 24).

Perhaps it is because so much of the designer's work is hidden that few studies have attempted to investigate their actual practice. Studies of expert designers (Akin, 1978; Darke, 1979; Eastman, 1970; Schön, 1983) have provided empirical descriptions and models. Recent studies of novice designers at the elementary level (Johnsey, 1995b; Outterside, 1993; Roden, 1995), at the secondary level (Kimbell et al., 1991), and at the university level (Elmer, 1996) are beginning to provide useful insights. Yet an enhanced understanding of the strategies of untutored students would undoubtedly exert some good influence on teaching. Hence the next section of this paper describes a method developed to investigate the strategies used by untutored designers.

Method

Ill-structured problem solving has been investigated using protocol analysis (e.g., Ericsson & Simon, 1984). Thus viewing the activity of "designing and making" as a particular form of problem solving allows for the adoption of protocol analysis as a research method in this study. Data were provided by the direct observation of, and retrospective interviews with, multiple cases.

The author's research referred to earlier in this paper (Welch, 1996; in press) involved students designing and making a solution to a specific problem entitled "Paper Tower". The design brief read as follows:

Using ONE sheet of 220 mm x 280 mm white paper and 100 mm of clear tape, construct the tallest possible tower. You will also be given pink paper. This you may use in any way as you develop your solution. However, NONE of the pink paper may be used in the tower you submit as a final product.

Limitations: There is a time limit of one hour. The tower must be free standing. It cannot be taped to the floor nor to anything else. When you have finished, the tower must stand for 30 seconds before having its height measured.

It is possible that the strategies used by students to generate a design proposal may have been a function of this particular design brief, the way it was presented, and the tools and materials available to produce a solution. In the follow-up study a quite different task and a wider range of tools and materials were provided to eight Year 7 students placed in single-sex dyads. Each dyad was given the following description of a context and design brief:

The Context: Your parents have invited your uncle, aunt and five year old cousin to visit and stay with you for two weeks. It so happens that your cousin's birthday falls on the second day of the visit. You want to give him/her a birthday present but unfortunately you are too short of money to buy one. So you have decided to make something as a surprise. You know that your cousin enjoys playing with toys that move, so you have decided to design and make one. Not only does this solve the problem created by having no money, but it offers the opportunity to give your cousin something really special - a toy you have designed and made.
Design brief: Design and make a moving toy that will amuse and intrigue a five year old boy or girl.

Students were given two hours in which to complete the task. Their designing and making was video and audio taped. The natural talk between the subjects was transcribed verbatim. A semi-structured retrospective interview, conducted with each dyad as they watched the video tape of themselves during the designing and making session, was also transcribed.

Transcripts of the natural talk during the design and make session were segmented into speech bursts. A description of the subjects' actions was added to the right of each segment. The time at which a change in the subjects' actions occurred was added to the left of each segment, thus allowing calculation of the duration of each period of action. A coding scheme (Appendix 1) was used to code actions of the subjects. The natural talk while problem solving and responses made during the semi-structured interview informed the coding. Those actions coded as designing and making were analyzed using descriptive statistics. This analysis provided the data for "mapping", using an XY scattergraph, the design strategy of each dyad. These maps provided a visual representation of the design process used by each dyad, which permitted a comparison between dyads in this study, between dyads in the two studies, and between all nine dyads and a map of the theoretical model.

Results

Figure 1 (see next page) shows the sequence in which Dyad 1 in the follow-up study employed elements of the theoretical model of the design process. The map shows quite clearly the dominance of three-dimensional modelling throughout the entire period when students were developing a solution. Equally clear is the iterative relationship between evaluating and modelling. The map shows how little time was spent at the beginning developing a solution by discussion or drawing and how quickly students moved to modelling with three-dimensional materials. This map is representative of the four dyads in the current study.

Figure 2 (see next page) is representative of the strategy used by the five dyads in the first study. The similarities between Figure 1 and Figure 2 are striking, and include: (a) the large proportion of time devoted to three-dimensional modelling; (b) the small amount of time spent generating alternative solutions, either by drawing or discussion; (c) the almost immediate move to three-dimensional
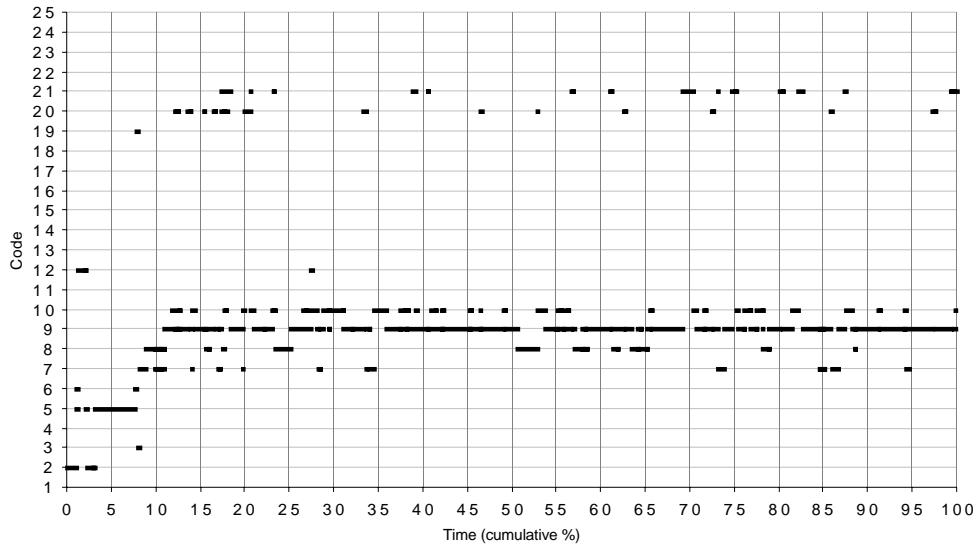
Figure 1 The Strategy used by Dyad 1 in study 2

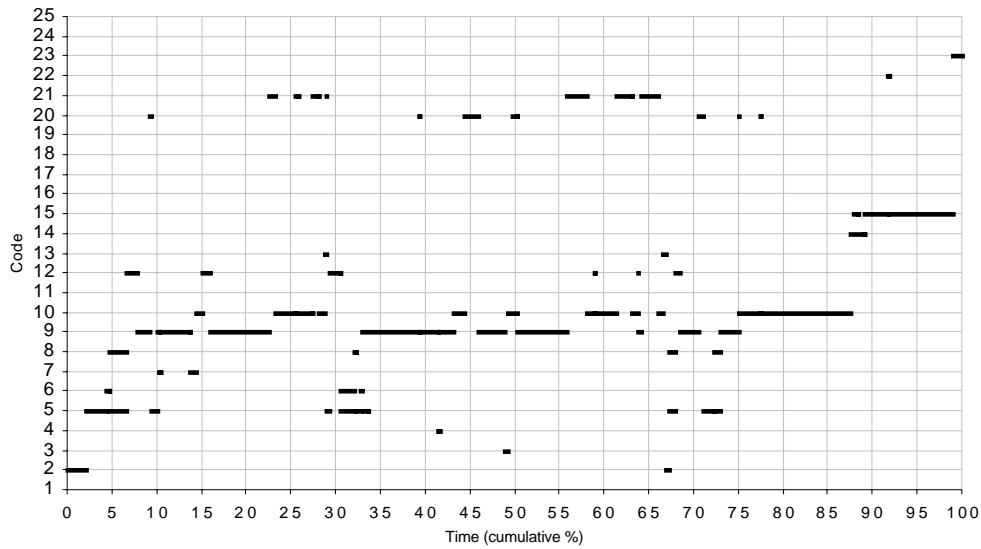
Figure 2 The strategy used by Dyad 5 in study 1

Legend

5 = Evaluate the solu

4 = Build a solution

3 = Model a possible
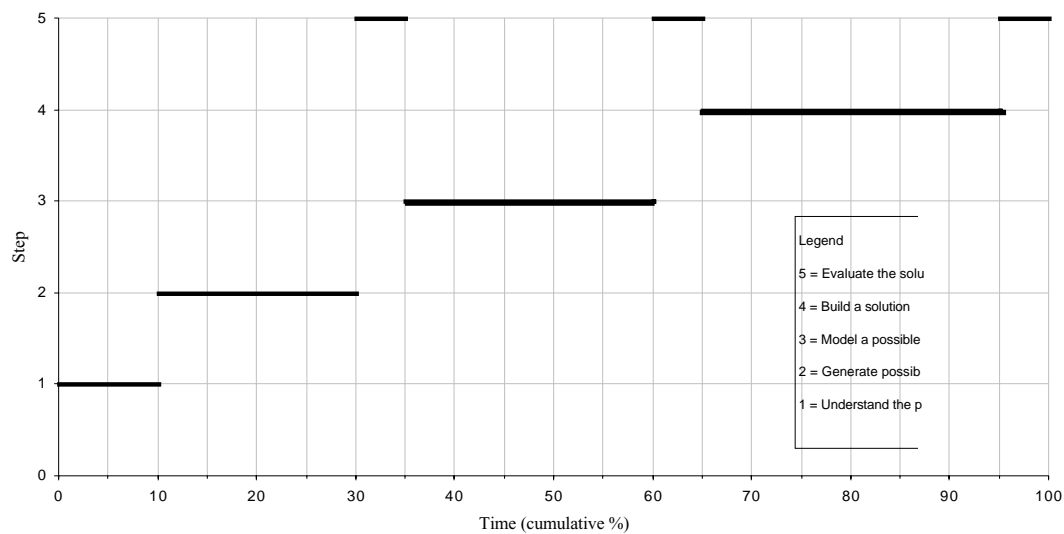
2 = Generate possib

1 = Understand the p

Figure 3 Map of the five-step theoretical design process used in this study

modelling to develop ideas; and (d) the frequency and consistency with which the developing solution is evaluated.

When the strategy used by each of the nine dyads is compared to a map of the theoretical design process (Figure 3), five significant differences are evident.

First, students' strategies are more complex than suggested by any of the models. They did not work in a linear way through the steps identified in textbook models. Understanding the problem appeared to emerge from an exploration of solutions. Students moved very quickly to solution generation. Students did not appreciate the importance of analyzing and focusing on the problem before "jumping straight to design ideas" (Harding, 1995, p. 19). Modelling was shown to be a complex activity, more accurately described by a model-test-refine-test iteration. This iteration itself appears to act as a source of inspiration for new solutions. Evaluation occurred not as a summative activity after generating and modelling and building, but as an integral and ongoing activity.

Second, students in these studies did not sketch several possible solutions in order to explore and evaluate their merits, a strategy prescribed by design process models. Sketching played an especially small part in the development of a solution. Nor was sketching viewed as a necessary first step in the development of a solution.

Third, it appears that the preferred strategy for developing ideas is modelling in three-dimensional form. Students moved to modelling much sooner than predicted by textbook models. The evidence suggests that novice designers are anxious to begin modelling, even before a solution has been fully worked out. This modelling served several purposes: externalizing ideas, providing a method of testing, refining and evaluating ideas, and stimulating new ideas. Modelling appeared to be an essential stimulus to the ongoing development of ideas.

Fourth, both Figures 1 and 2 illustrate how evaluating was an integral and ongoing activity

when students in these studies were designing. Evaluating occurred consistently from the earliest moments of designing. Finally, students in the second study made no distinction between modelling a solution and building a prototype. Except for a brief period of sketching by Dyad 1 students did not use either two- or three-dimensional modelling as a preliminary to making. In other words, for these students the model was the prototype

Discussion

The most significant result to emerge from the follow-up study was to confirm the critical role of modelling in three-dimensional materials as an aid to students' thinking. Modelling was used to support a range of activities: increasing understanding of the problem, stimulating the generation of solutions, seeing what a design would look like, testing, and continuously incorporating modifications and improvements into a solution. Yet this result contradicts the strategy proposed by most design process models: that students sketch several possible solutions before moving to modelling in three-dimensional materials. Clearly the results of these two studies suggest that teachers must think carefully about the teaching of two-dimensional and three-dimensional modelling skills. It appears important to provide students, early in the process, an opportunity to explore, develop and communicate aspects of their design proposals by modelling their ideas in three-dimensional form.

The results also reveal good reason to doubt the efficacy of requiring students to follow any form of linear or sequential design process model. Both studies have shown that untutored designers do engage in many of the sub-processes of theoretical models, but do not prioritize or sequence these sub-processes as suggested by the models. This suggests a need for teachers to explicitly teach process skills which will assist students' designing, but which do not impose a strict sequence in which those skills are applied. Recent research by Stables (1997) also suggests "the importance of children working in a responsive, rather than a prescriptive, manner when engaged in designing and making" (p. 11). Yet at the same time, as Kimbell (1990)

has described, students must be provided with a superstructure to designing. They must be able to think and work strategically, so that when time runs out at the end of a project they are where they want to be. Hence designing combines dynamic thinking within the project with the metacognitive task of being able to stand back and have an overview of the whole that will lead to a satisfactory conclusion.

The follow-up study also confirmed the dominant place of evaluating as students were designing. It appears that teachers need to focus the attention of students on this activity and stress its importance. Ongoing evaluation is likely to increase the quality of both the end product and the ability of the student to design effectively. A recognition of a model-test-refine-test iteration so dominant in the strategies used by subjects should, as Johnsey (1995b) has also found, encourage teachers to take a broader view of the nature and role of evaluating when students are designing.

Finally, the absence of a distinction between modelling and prototyping by students in the second study indicates the importance of the form in which tasks are presented to students. The task in Study 1 clearly indicated the need to differentiate between a "developing solution" and a "final product". Additionally, different materials were provided for the solution and the product. In Study 2 no such distinction was made. Making was an ongoing part of the process, fully integrated with other design process skills.

Conclusion

The two studies reported here provide a detailed examination of the strategies used by untutored students working in single-sex dyads to produce a design proposal. Both studies show that significant differences exist between the strategies used by novice designers and theoretical models contained in many textbooks and curriculum documents.

The results suggest that teachers must think carefully about the way in which students are expected to explore, develop and communicate their design proposals, and that

teaching any form of linear design process may be counter-productive to students' success in developing a solution to a design-and-make task.

References

- Akin, O. (1978). How do architects design? In J-C Latombe (Ed.). *Artificial intelligence and pattern recognition in computer-aided design* (pp. 65-104). New York: North-Holland.

- Breckon, A. (1995). DATA annual conference address. *Design & Technology Teaching*, 28(1), 11-16.

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

- Darke, J. (1979). The primary generator and the design process. *Design Studies*, 1(1), 36-44.

- Eastman, C. M. (1970). On the analysis of intuitive design processes. In G. T. Moore (Ed.), *Emerging methods in environmental design and planning. Proceedings of the Design Methods Group First International Conference* (pp. 21-37). Cambridge, MA: MIT.

- Elmer, R. (1996). *Whose need?: A study of the reflective practice of eight students on a BA honours design and technology course*. Unpublished doctoral dissertation, University of Reading, Reading.

- Ericsson, K. A. & Simon, H. A. (1984). *Protocol analysis: Verbal reports as data.* Cambridge, Mass.: The MIT Press.

- Harding, R. (1995). Professional designers in primary schools: How successful are they at teaching children design skills? *Design and Technology Teaching*, 28(1), 19-21.

- Johnsey, R. (1995a). The design process - does it exist? A critical review of published models for the design process in England and Wales. *International Journal of Technology and Design Education*, 5, 199-217.

- Johnsey, R. (1995b). The place of the process skill making in design and technology: Lessons from research into the way primary children design and make. In J. S. Smith (Ed.), *IDATER95: International Conference on Design and Technology Educational Research and Curriculum Development* (pp. 15-20). Loughborough: Loughborough University of Technology.

- Jones, J. C. (1970). The state of the art in design methods. In G. T. Moore (Ed.). *Emerging methods in environmental design and planning. Proceedings of the Design Methods Group First International Conference* (pp. 3-9). Cambridge, MA: MIT.

- Kimbell, R. (1990). *Design and technology starters: Teaching and learning procedures, issues for INSET* (video recording). Kent: Kent County Council.

- Kimbell, R., Stables, K., Wheeler, T., Wosniak, A., & Kelly, V. (1991). *The assessment of performance in design and technology: Final report.* London: Schools Examination and Assessment Council.

- Lawson, B. (1990). *How designers think: The design process demystified* (2nd ed.). London: The Architectural Press.

- Outterside, Y. (1993). The emergence of design ability: The early years. In J. S. Smith (Ed.), *IDATER93: International Conference on Design and Technology Educational Research and Curriculum Development* (pp. 43-49). Loughborough: Loughborough University of Technology.

- Roden, C. (1995). Young children's learning strategies in design and technology. In J. S. Smith (Ed.), *IDATER95: International Conference on Design and Technology Educational Research and Curriculum Development* (pp. 20-27). Loughborough: Loughborough University.

- Schön, D. A., (1983). *The reflective practitioner: How professionals think and act.* New York: Basic Books.

- Simon, H. A. (1973). The structure of ill-structured problems. *Artificial Intelligence*, 4, 181-201.

- Siraj-Blatchford, J. (1993). Constructing design and technology: An early years perspective. *International Journal of Technology and Design Education*, 3(3), 19-30.

- Stables, K. (1997). *Out of the mouths of babes: Creative thinking and children designing.* Paper presented at the Third International Conference on Creative Thinking, Malta.

- Welch, M. (1996). *The strategies used by ten grade 7 students, working in single-sex dyads, to solve a technological problem.* Unpublished doctoral dissertation, McGill University, Montreal.

- Welch, M. (in press). Students' use of three-dimensional modelling while designing and making a solution to a technological problem. *International Journal of Technology and Design Education.*

Appendix 1   Codes to describe designing

Step	Code	Definition
Understanding the problem	RBRF	Reading design brief as given to subjects by researcher
	DPERF	Discussing/referring to performance criteria
	DCONS	Discussing/referring to constraints
Generating possible solutions	GEN	Discussing possible solution
	DRAW	Sketching/drawing possible solution
Modelling a possible solution	PMU	Planning the making of a mock-up
	MANIP	manipulating materials to explore one element of a possible solution
	MMU	making a mock-up
	RMU	Refining a mock-up: making modifications to current solution
	CMMU	Making a copy of a previous mock-up
	ARM	Checking available resources and materials
	ABAN	Abandon current solution: begin new solution
Building a prototype	PPR	Planning the production of a prototype
	MPR	Making a prototype
	IPPR	Identifying a problem with a prototype
	MODPR	Modifying and improving the prototype in terms of the original need: i.e., making a design change
Evaluation	EGEN	Evaluating as subjects talk about a possible solution
	EDRAW	Evaluating as subjects talk about a sketch or drawing
	TMU	Testing one element of a mock-up in terms of the design brief
	EMU	Evaluating mock-up on terms of design brief
	TPR	Testing one element of the prototype as making continues
	EPR	Evaluating the prototype in terms of the design brief
	RRMU	Recording results from mock-up
	RRPR	Recording results from prototype