Primary School Students Approaches to Design Activities

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Sarah J. Stein*, Campbell J. McRobbie#, and Ian S. Ginns#

*Teaching and Educational Development Institute (TEDI)

The University of Queensland

St Lucia QLD 4072 Australia

#Centre for Mathematics and Science Education

Queensland University of Technology - Kelvin Grove

Victoria Park Road

Kelvin Grove QLD 4059 Australia

Email: s.stein@uq.edu.au

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Sarah J. Stein*, Campbell J. McRobbie#. and Ian S. Ginns#

*University of Queensland

#Queensland University of Technology

Abstract

There is little documented evidence about the actions and the processes engaged in by novice designers of primary school age students. The study described in this paper attempts to fill that gap by presenting a graphical notation which was used to provide a picture of students' design actions. The notation, developed from an earlier version used to analyse science students' activity, and used to map the designerly thinking and action of pre-service teachers, is used to present insights into the designing actions of small groups of Year 6 students, who were involved in open-ended design and make projects. The graphical notation supported the analysis of the development of the students' designing actions and associated ideas across the period of their design projects. Some insights provided by the maps of the students' activity included the heavy reliance of students upon the concrete realities they were creating and developing as their designing took place, and the differences in the overall activity as some groups made decisions early and adhered to them, while others made many alterations along the way. The analysis of the students' actions in this way provides educators some detailed information about the nature of design processes primary school students actually use, an advantage, we suggest, over assumptions using theoretical or empirical models derived from professional designers' actions.

Theoretical Framework

Technology as a learning area with a design and problem solving emphasis is becoming increasingly common in primary school curricula around the world, including in Australia (Curriculum Corporation, 1994). With design being such a strong aspect of these curricula, it has been recognised that there is a need for teachers to know more about school students' designing abilities and the processes they use as they engage in technological activity (Johnsey, 1995). One way of assisting teachers in the task of supporting their students within design and technology learning contexts is to provide them with information about what their students are actually doing when they engage in design and technology activities.

Many attempts have been made in the professional world of architects and engineers to expose and delineate the various methods, strategies, and thinking processes designers engage in, and draw upon, as they design. As a result of some of these studies various design methods have been devised to provide guidelines that aim to assist designers improve their skills (e.g., Altshuller, 1988; Matchett, as cited in Jones, 1992). Forms of these often sequenced steps and models, have been used in educational texts as guides for school teachers planning for technology learning experiences in their classrooms (e.g., Open Access Support Centre, 1996). However, the limitations of these sequenced models also have been noted, especially with regard to their usefulness for guiding teaching (Middleton, 2000; Welch, 1999) because they can present an idea of technological activity that is artificial. Rather than being followed, step-by-step, these models need to be viewed as sources of information that can provide general overviews of the types of activities that tend to occur during most design and problem solving activities. Useful insights into design activity can be gained from the research being undertaken into novice and expert (adult) designers (e.g., Kavakli & Gero, 2002; Oxman, 1999), as cognitive actions are analysed and compared across groups. Once again, these studies confirm that design activity is complex and not easily describable or delineated. As technology education with a design emphasis has become seen as part of normal school curriculum, there has perhaps been a growing over-emphasis upon design (Mawson & Maor, 2001). We suggest that it is important for investigations to continue into how primary school students actually design, so that greater understanding about the relative place and importance of design within the whole of technology will emerge and thus help researchers and teachers to redefine design and incorporate design and technology learning opportunities more appropriately within classroom situations. It is important that classroom teachers recognise that design activity is complex in nature, yet not be overwhelmed by that complexity, such that they are not alert to the situations or events where students' learning can be scaffolded or supported.

As well as sequences of steps and methods, design activity has also been viewed as incorporating types of knowledge, drawn upon, selected, manipulated and utilised in different ways according to task, purpose and context. We have used Faulkner's (1994) knowledge types in a number of studies to help us to analyse and understand the knowledge of design and technology being generated and used by teachers and students in primary school settings (e.g., Ginns, Stein & McRobbie, 2000; Ginns, Stein, McRobbie, & Swales, 2000) and in undergraduate information technology students at university (Stein, Docherty & Hannam, 2001). While these knowledge types have been useful to provide a broad framework of understanding, we believe that an even better understanding of design and technology classrooms can emerge through a complementary and closer analysis of specific episodes of design activity.

Our past study into the specific design actions of pre-service primary teachers (McRobbie, Stein & Ginns, 2001) was an attempt to do just that. In that study, we recognised the limitations of staged, sequenced design methods to describe design activity, acknowledged the valuable insights provided by Jones and Carr (1993) (NZ) and Kimbell, Stables and Green (1996) (UK), as well as the analyses reported by Welch (1999) of the design activities of grade 7 students and Roden (1999), who developed a taxonomy of very young students' design activities. Our 2001 study drew on the ideas of Gooding (1992) and Roth, McRobbie, Lucas and Boutonné (1997) and applied them in a different theoretical frame of reference to produce a new notation whereby the design activities of students could be mapped (McRobbie, et al., 2001). The mapping notation served to identify three levels of problems, which emerged during the design activity of the pre-service primary school teachers who were novice designers. The three problem classes identified were on macro, meso and micro levels, similar to those identified by McCormick, Murphy, Hennessy and Davidson (1996) and Roth (1995). They are described in Appendix 1. Three types of *seeing* were also identified: *seeing that*, *seeing as* and *seeing in*, which were similar to types of seeing which make up *move experiments* or local units of a design process and described originally by Schön and Wiggins (1992). These three types of seeing are described in detail in Appendix 1.

Each level of problem and type of seeing was revealed through the actions and/or words of the pre-service teachers as they engaged in small group, open-ended and loosely defined design and technology activities. Resultant maps, using a series of symbols, described in detail in Appendix 1 of this paper, re-presented the levels of problems and the move experiments, as the pre-service teachers saw, took a step and saw again (Schön & Wiggins, 1992). The maps provided a picture of the design activity and a re-presentation of "reflective 'conversation[s]' with the materials of [the] design situation" (Schön & Wiggins, 1992, p. 135). The maps showed the designerly thinking and actions of the pre-service teachers at different grain sizes from the macro structure of episodes of attention, to various aspects of the design problem, to more detailed microanalysis within an episode. They represented action in terms of the novice designers' transformation of ideas, their search for new relationships among ideas, materials, tools and developing designs, their reassessment of each situation (Jones, 1992) and their collaboration to reach consensus.

The purpose of the current study, therefore, was to make use of the mapping notation again, within the broader framework of Faulkner's (1994) technology knowledge types, to explore the designerly thinking and actions of primary school student novice designers, engaged in open-ended design and technology tasks. Through this means, it was aimed to analyse the students' thinking and actions on a more fine-grained level than had been reported elsewhere.

Design and Methods

In order to focus on the phenomenon of the designing processes used by the primary school students, basic elements of phenomenological thought (Holstein & Gubrium, 1998) formed the underpinning assumptions the researchers made about the circumstances of the technological activity in which the students were engaged. Simultaneously, an interpretive research methodology (Erickson, 1998) framed the interactions between the researchers and the participants, so that the researchers could understand the thoughts and actions of the students as they engaged in their design and technology activities. The criteria of trustworthiness, authenticity and the benefits of the hermeneutic process (Guba & Lincoln, 1994) were used to monitor the quality of the interpretive inquiry.

Participants

The participants were two Year 6 classes at a primary school situated in south-east Queensland, Australia, led by their teacher for technology education, Anthony (all names are pseudonyms). Anthony, like most primary school teachers in the state, had had limited experience in teaching design and technology, as the key learning area of technology is a new addition to the curriculum and is only to be introduced into primary schools formally in 2002 (Queensland School Curriculum Council, 2002). The two classes of 30 students each were combined for the technology lessons. While Anthony planned and led a technology unit of work that he had prepared, the other Year 6 teacher assisted. The school's teacher-librarian, Joseph, provided further assistance. The students were interviewed about their conceptions of technology and their predictions and understandings about what technology education involved at the beginning of the unit of work. Six focus students were selected to represent the range of responses on the surveys and interviews, and upon the teacher's advice as being students who would be capable of providing thoughtful feedback on their designing experiences. The members of the two focus groups were Maria, Janine and Rita in Group 1, and Ben, Chris and Trevor in Group 2.

Data Sources

Data sources for the study were: student responses to technology survey instruments (Rennie & Jarvis, 1994); pre - and post interviews that probed the students' understandings of technology and design and all interviews were audio taped; video and audio recording of the two focus groups of three students each (using radio microphones) as they undertook their design activities during the technology lessons; field notes from observations of students by the research team as the students undertook their design activities; and, artefacts, such as worksheets completed by the students during the course of the unit. References to relevant data sources are made in parentheses within the descriptions and discussion in rest of this paper.

The Classroom and the Unit of Work

The two Year 6 classes occupied one large room and much of the designing and making activity took place there. A smaller workspace adjoined the large classroom. This was used for storing equipment and materials and also provided access to water, a stove and three, large worktables. Anthony used this adjoining room for displaying the materials for use and as a space for the students to cut, hammer, drill and glue their materials during construction times. The materials available to the students included beads, string, nails, wood, plastic, pieces of styrofoam, some in wedge shapes, plastic wheels of two different sizes, short cylindrical metal rods for axles, plastic propellers that could fit onto the end of pieces of dowel fitted with a hook and elastic band. The tools available included hammers, hacksaws, a glue gun and a hand operated drill. An electric drill was also available, and Joseph operated this for the students.

The unit of work implemented by Anthony was made up of two main parts. In the first part, Anthony provided structured guidance combined with some open-ended activity to support the students' development of ideas and skills and to assist them to gain some design knowledge, which would help them in the major task that was to be set later in the unit. These structured and guided activities included, for example, discussion about the construction of self-propelled, model boats; demonstration and display of boats Anthony and Joseph had constructed previously; a discussion about the difficulties that had arisen for Anthony and Joseph in the selection and use of materials and tools; sharing ideas amongst students and teachers for the building of model boats; and how to improve the boats' running speed through varying aspects of the construction. Demonstration trials of the previously constructed boats were held in the school's swimming pool.

The more open-ended aspect of this first stage of the unit of work consisted of an opportunity for each small group of three students to build its own self-propelled boat using a wooden block measuring 15 cm x 10 cm x 1 cm as a base (hull). During discussions, the students had been exposed to a variety of available materials and tools, and they were able to choose from the selection to make the best running boat they could. This was what Anthony called "the investigation" stage.

> I think the biggest part...[is] the investigating stage. You have to equip the children with the knowledge to design something. You can't just send them in cold...because their knowledge base in most of these areas is very small. (Anthony - interview prior to the commencement of the unit of work)

He believed that there was need to allow students to explore notions and gain information that would be helpful when they began to hone their ideas.

In order to plan for the boat building, Anthony asked the students to develop design briefs first, just as he had done before building his demonstration models. He showed the design briefs that he had developed to the students as examples to guide them in this task. The development of a design brief was one way in which Anthony introduced his students to design practice (Faulkner, 1994). The students had to draw diagrams of their designs; a top view and a side view, and write a description of the features of their designs. They were encouraged to discuss ideas, and look at and handle the available materials at this point. While Anthony knew that the students' designs would develop and change as they began working with the materials, he encouraged them to complete their design briefs before they began constructing. He believed that this way the students would see the advantages of early planning and recognise the need for gathering information to inform their designs and to result in a better quality outcome (Field Notes). Anthony also hoped that there would be less wastage of materials. At this stage of the unit, Anthony provided definition for the task, by describing the expected outcome and placing a limitation upon the activity, namely, through providing a pre-cut piece of wood to form the hull of the boat. Thus, the activity had some definition, but was, at the same time, open-ended.

In the second part of the unit of work, the open-ended task set by Anthony was for the students to design a self-powered vehicle. The task thus was less defined than the last one. They were to work in the same groups of three as they had worked in during the boat-building task. The students worked on their self-powered vehicles during school time predominantly, although some took their constructions home and worked on them there. To finish the unit, the criterion established for the groups was that the vehicle should be able to travel a distance in excess of two metres under its own power. The students demonstrated the speed and travel distance of their vehicles to the rest of the Year 6 students and to a number of other classes from the school.

Analysis

By matching the video recordings of student action, the transcriptions of student talk within their working groups, and field notes recorded by researchers, maps of the students' designerly thinking and action were developed, using the process described in McRobbie et al. (2001). The resultant maps were analysed in the light of the students' development of technological knowledge in terms of the broader framework provided by Faulkner's (1994) knowledge types. Student knowledge development was also evident in their expressions of understanding, which emerged through the student interviews. Excerpts from the interviews, from recordings of teacher and student interactions and from field notes of general and particular classroom activity were used alongside the maps to assist in the analysis of the student designerly activity and knowledge development.

Results

The results of this study are presented in the form of assertions describing the designerly thinking and actions of the students, drawing on the constructed maps, using the notation devised in our earlier study of pre-service teachers (McRobbie, et al. 2001) and other data sources.

Assertion 1: The influence of the initial design thinking on the final artefact could be seen throughout the course of the group activity. It focussed the students' thinking about the task.

The influence played by the design brief upon the general movement through activity to the achievement of outcomes by both groups was notable. Both groups spent time early in the second part of the unit of work, developing specifications for a self-powered vehicle, as their teacher had instructed them. While both groups drew their diagrams, there were certain aspects of those diagrams to which they could not add specific detail (Field Notes). These aspects formed problems on meso and micro levels, which caused changes of direction at times and alterations to the macro problem (original design briefs). The maps in Figures 1 and 2 show that, across the activities that took place during the second part of the unit of work, for the two focus groups alterations were made at the macro level because of problems encountered at the meso and/or micro levels.

Figure 1 shows the overall progression of the three levels of problem solving undertaken by Group 2, (Ben, Chris and Trevor). The members of Group 2 wanted to include a battery powered motor in their vehicle (their first macro problem shown at the top of the map in Figure 1), but could not include fine details of how the motor was going to drive the wheels. Rather, during the initial design/drawing discussion, the focus of much of that group's talk was on the appearance of the vehicle, with some reference being made to the shape of the body having influence over the aerodynamic capabilities of the vehicle (Video). The students saw the task of fitting the motor in their vehicle as a problem to be solved during the constructing time, rather than one to be solved during the drawing (initial design) time (Field Notes).

The focus of Group 2's eventual activity became fitting the motor and battery to the car and designing an assembly to enable the wheels to be powered (the first meso problem and subsequent two micro problems shown in Figure 1). The students in this group faced difficulties in achieving their aim and became easily distracted and frustrated (Field Notes). When, towards the end of the period allocated for the unit of work, the group had not progressed very far towards having a completed vehicle, Anthony suggested that they change their ideas because it was clear that their plans could not be operationalised. He believed that "the process is the most important part" of a technology activity (Initial interview) and he wanted to emphasise that in his unit of work. He wanted to show the students that it was important, for example, to balance design criteria with practical considerations (Faulkner, 1994), and, where the difficulties faced by Group 2 were concerned, suggested that the students accept that they had come across a problem that they could not solve, and that they should change their design brief (alter their macro problem). The following excerpt taken from the video account of the lesson during which the students faced this challenge illustrates how Anthony tried to suggest to the students that they needed to recognise that they had to consider other options.

Anthony: Okay so the motor's not going to work.

Chris: Nup.

Anthony: What are other options?

Chris: Propellers.

Trevor: Wind powered?

Anthony: Propellers, balloons.

...

Anthony: Now you've given yourselves a smaller car than everyone else. What's that going to enable you to do?

Trevor: Go a bit faster 'cos it's lighter.

Anthony: It's going to be lighter, that's right. But you're also going to have to think about your power source. What type of power source?...What's going to be better, balloons or propellers? (Video of second last lesson of the unit)

The group then decided upon a new macro problem, which resulted in their creation of a balloon-powered vehicle, completed within a very short time (approximately 15 minutes - Field Notes). However, the group was not satisfied, particularly because the balloon car did not go as fast as they would have liked. The students adhered to their belief that the original idea expressed in their first design brief should be able to work. They were still determined to achieve the plans they had drawn up in their design brief. During one weekend, one of the group members worked on the problem with his brother and returned to school with an assembly that connected the drive of the motor directly to the axle of the vehicle. The students then found it relatively straightforward to build the assembly into their vehicle. They achieved their aim of incorporating a motor into their vehicle and they completed the task on time. In doing so, they solved their original macro problem.

During the course of the activity, there were many times when the students did not appear to be "on task" and struggles between the members occurred in relation to agreement about how the vehicle should look and how the various components to house the motor would be constructed (Field Notes). However, in viewing the overall map of the group's activity across the period of the second part of the unit, as shown in Figure 1, they strayed little in a macro problem sense from their original plan of designing and constructing a motor driven vehicle.

Similarly, the members of Group 1 (Maria, Janine and Rita) were determined to adhere to their original plans. Their first design brief was of a car powered by a wound up elastic band and incorporating a propeller, their macro problem, as shown in Figure 2. While they were able to solve the meso problem of attaching the propeller to the car, they experienced much more difficulty with the micro problem of attaching the elastic band and positioning it in a way that enabled a smooth release. Thus, Group 1 altered its macro problem to one that incorporated the development of a car driven by wind (balloons). This is shown as the second macro problem in Figure 2.

While Group 1 students were able to solve the meso problem of attaching the balloons to the car, they faced the micro problem of controlling the flow of air from the balloons. They wanted to introduce a mechanism to slow down the release of the air, as well as one to enable them to blow up two balloons and release air from them simultaneously. Once again, they reviewed their macro problem (design brief specifications). They decided that because they had had little difficulty in attaching one propeller to the car earlier, and that the propeller had worked well, more than one propeller might satisfy their needs to create a vehicle that moved much more quickly than before. (During the course of the activity, they had realised that one propeller would not produce sufficient speed to compete with other students' developing vehicles). Ultimately, the students achieved this end and they produced a car that was powered by three propellers.

Thus, in this second part of the unit of work, during which the students were given freedom to alter aspects of the macro problem, the students responded to the opportunity to plan early and to adhere to those plans as closely as possible. Those macro problems they set for themselves, enunciated through their design briefs, then guided the overall direction of their activities.

Assertion 2: The students displayed behaviours that included trial and error and generation and test procedures.

Trial and error procedures, that is, finding solutions to problems in an entirely random manner (Rowe, 1987), were used at times by the focus groups. There were some, but fewer instances of the use of generate and test procedures, that is, actions taken in response to attempts to generate solutions to the defined problems emerging with the progression of action (Rowe, 1987). Figure 3 is an excerpt of the map of Group 1's endeavours to develop a paddlewheel for their boat during the first part of the unit of work. The map in Figure 3 shows that the students put forward a series of ideas about the size of the paddles, as they tried to solve the problem of ensuring that when the paddles were fitted into the wheel (a CD) and attached to the boat, they would move through the water at an appropriate depth to cause the boat to move forward. The students tried to attain the right paddle size, by viewing the paddles and imagining the size they should be. At the same time they were wrestling with where on the boat to attach the paddlewheel. The students were not able to predict with very much certainty the depth to which the paddle would sit in the water if they removed a small part of the paddle. Rather than make predictions based on reasoned thought about, for example, where the level of the water would be in relation to the hull of the boat and the uprights they had included in the paddlewheel assembly, or the effect of the weight and size of the assembly and the rest of the boat on the displacement of water, they tended to try ideas and see if they worked. This can be seen through the interchange at the start of the excerpt in Figure 4. References to making the paddlewheel "lower, much lower" and statements such as, "cut off a piece of [the top of the paddles]" indicate that the students were not incorporating any information or knowledge other than the experience of the developing artefact and materials in front of them at the time.

On the other hand, the students relied on the occasional idea that affirmed and assured them that they were heading in a direction that was moving them closer to achieving a successful outcome. Occasionally, one of the students would make some assertion that influenced the direction of thought. For example, when M suggested, " We could dig - like we could make it so that stays in there and put a little ditch [on the upright supports for the CD]," the idea that the depression they made in the uprights would change the height of the wheel was suddenly revealed and they then had to factor that into their deliberations. This instance led J to stating later, "This'll do, I hope," as she tested the paddle on the uprights again and rolled the paddlewheel down about 1 cm indicating a smaller cut than the 2 cm the students had been talking about making previously. Meanwhile, R had suggested 2 cm was the amount to trim off and did not stray from that opinion until, at the end of the excerpt in Figure 3, it became evident to her that 1 cm was a more appropriate amount to trim off - "I suppose we don't really have to take that much off, just a centimetre."

The diagram in Figure 3 indicates a large number of *"seeing as"* proposals (physical plus mental envisioning) that did not develop or lead directly to *"seeing in"*(envisioning about physical phenomena plus mental activity with a conclusion) proposals (see descriptions of the different types of seeing and the symbols used to represent them in Appendices 1 and 2). The students concentrated upon many tryouts, with few controlled planned predictions about outcome (generate and test procedures). This behaviour is very like the actions of adult novice designers, as reported by Kavakli and Gero (2002). In that study, successful outcomes and even discoveries were found to emerge from the design activity of novices. However, their study also showed that experts displayed more control over the number of moves or trials in their designerly explorations. Novices, on the other hand, tended to engage in far more moves, tryouts, or cognitive action sequences (Kavakli & Gero, 2002).

Where the teacher, Andrew's, role was concerned, it was at these times when opportunities to concentrate attention on elements within the activity/problem could have been made explicit for the students. While it is acknowledged that allowing the students to work through their difficulties on their own can contribute positively to their learning, the observation is also made that in the instance described above, aspects of knowledge about the natural world and knowledge about developing and testing procedures (Faulkner, 1994) could have been the focus for teacher intervention. Support and scaffolding from the teacher would have had the effect of helping the students to direct their thinking towards making predictions and testing them, rather than relying, as they did at times, on trial and error strategies.

Assertion 3: The interaction with the materials was an important part of the design process as the students thought through their tasks and tackled the problems that arose.

At the commencement of the first series of lessons focusing on the construction of a model boat, all groups were provided with a rectangular piece of timber, which they were to use as the starting point for designing and building the boat. Their initial task was to shape the timber into the hull of the boat. Joseph used a power saw to cut the timber to the respective shape designed by each group. Each group then prepared a design brief, in which they had to consider the means of propulsion of the boat and other fittings they might wish to attach to the deck of the boat. A drawing of their vision of the completed artefact was an important component of the design brief. A model boat constructed by the Joseph was displayed as an exemplar for the students to examine and evaluate, and use as a potential source of ideas for their own work. For all groups, timber was the material at hand for the hull of the boat. A range of materials, such as balsa wood, styrofoam, cardboard, and aluminium discs, was available for use to construct the boat's propulsion system and other fittings for the deck of the boat.

The focus of the second series of lessons was the engagement of the groups in a less structured project, in which they were given the task of designing and constructing a model car that could move. The criterion established for the groups was that the car should be able to travel a distance in excess of two metres under its own power. In contrast to the model boat, no materials were prescribed for the body of the model car. The range of materials at hand for constructing the model car was similar to that described for the propulsion system and fittings of the boat.

Both focus groups were able to make some predictions about their final products, which they represented in the form of design briefs, including drawings of what the artefact would look like. However, they needed to work with, examine and manipulate materials physically in order to be sure that they could transform their ideas into concrete realities. Apart from the initial design brief, very few sketches were made to indicate what they intended to do, or what they had done, as they proceeded with the construction of the respective artefacts. Much modelling with materials at hand was undertaken as they grappled with, for example, finding the best location of a paddlewheel to propel a model boat (see Figure 3), and joining wheels to axles and attaching the wheel-axle systems to the body of a model car for best operating performance (see Figure 4) (Field Notes). These observations are in accord with the findings of Welch (1999) who pointed out the critical role that modelling in three-dimensional materials played in the design activities of younger novice designers.

The manipulation of materials occurred in conjunction with discussion that included conjecture about the appropriate configuration of the component parts of an artefact, testing procedures, and predictions about the results of various actions. Often, the names of equipment, materials, assemblies and so on, were not used, but non-verbal actions such as gestures, pointing and handling of the objects, served to assist the conceptualisation and communication of ideas and intents between and amongst the group members. Furthermore, it was because the group members were able to manipulate the materials and tools, and share ideas and intents that they were able to make decisions about the steps to take and changes to enact during the construction of their artefacts. While they were given the opportunity to plan their ideas early on, it was only when they actually began to manipulate the materials and other resources and observe the physical realities they were creating that the workability of their ideas was revealed. They needed to have the physical realities of the materials and tools before them so that they were able to touch and manipulate them (see the discussion of Assertion 2).

It was necessary for the students to manipulate the materials that they were working with in order to be able to realise the limitations and possibilities of the resources available to them, that is, discover the properties of materials (Faulkner, 1994), and also their own technological skills and abilities. Through physical contact with the materials and the tools, the students demonstrated that they were engaged in processes involving an interaction between the mind and the hand (Black & Harrison, 1992), something also highlighted by Kimbell et al. (1996) and Jones and Carr (1993) in their studies. Sequenced and staged models and methods of design processes cannot explain adequately the processes, in which the students were engaged, a finding in accord with that of Welch (1999) and Roden (1999). The students developed plans at the very early stages of each project, and they also continued to plan, construct, review and evaluate the physical constructions throughout the course of each project. Their ongoing plans tended to be embodied in their actions. They sometimes concentrated on several aspects of the tasks before them, attempting to solve these problems simultaneously, as they became relevant. The solving of their overall problems were achieved within the boundaries of the task, time, materials, their own skills and abilities, and, in particular, the materials at hand.

Assertion 4: The designing and constructing experiences provided opportunities for students to develop knowledge about some aspects of design practice, but did not necessarily result in the development of explicit knowledge.

Across the maps there were few move experiments that indicated students' development of explicit knowledge about design, particularly knowledge about the natural world (Faulkner, 1994). One indication of this is that in the maps of the two focus groups' activities, there are few occurrences of the symbol representing *seeing in*, which is used to indicate that participants have drawn ideas together, are able to see (envision) the possibility of the situation/phenomena as being different, are able to make the foreseen transformation in a concrete way and explain how and why the transformation works. In this case, this includes being able to envisage and explain trade-offs (*seeing in*). Figure 4 shows an excerpt from the map of Group 2's activities during which move experiments were made to solve the problem of attaching the wheel and axle assembly to the styrofoam body of the car they were making. The group members eventually decided that threading the axle through a piece of straw and sticking the resultant axle/wheel/straw assembly to the car body with tape stuck across the straw would work best. The map indicates that while the axle/wheel/straw assembly idea developed to a point where it did indeed solve the micro problem at hand, there was no point at which the students' words and actions indicated that explicit knowledge developed about why the assembly worked (only one *seeing that* symbol appears in the map excerpt in Figure 4). The students could identify merely that it did indeed work. The lack of explicit knowledge about how the straw helped to reduce friction, for example, is further supported through the statements made by two of the group members during follow up interviews.

Interviewer: So how does the straw help, then?

Ben: It lets you able to stick it on with masking tape, but the axle can still spin.

Interviewer: So what's the inside of the straw like that means it can spin easily?

Ben: Because the axle fits through it nicely and it can spin without going from side to side.

Interviewer: So there's something about the straw that enables it to spin.

Chris: Yeah.

Interviewer: What might that be?

Chris: Well, because we put the axle straight through the straw, if we just like - and we sticky taped the straw on instead of the axle. If we just sticky taped the axle on, it's not as if the car would move.

Interviewer: So the tape would hold back the axle?

Chris: Yes.

The students were "seeing" the axle, wheels, straw and styrofoam car body from an artefactual level, not at a level which indicated abstracted knowledge of the natural world (Faulkner, 1994) (e.g., that one of the reasons why the straw facilitated the turning of the axle had something to do with friction reduction). At this point of the design and make activity, there existed a teaching opportunity to capture a meaningful moment during which the learning about, say, friction, and specific properties of the materials being used, could have been made explicit for Group 2 students, and their understanding could have been encouraged to move to a world knowledge level (Roth, 1998; Roth et al., 1997), that is, a World 3 type of knowledge (Popper, 1972) of theories, explanations, solutions, proofs and so on, that have already been produced and exist as immaterial "objects" (Bereiter, 1994). Crismond (2001), in his study of naïve, novice and expert designers, also noted that in the design activity of all the groups he studied, there was much more concentration upon strategies which involved analysis than there was upon evaluation or synthesis. In addition, Crismond noted that the non-expert designers in particular, tended not to recognise the emergence of concept and process knowledge without scaffolded assistance through directed (teacher) questioning.

Educational Significance

The mapping of the Year 6 students' design processes using an adaptation of the notations originally devised by Gooding (1992), developed by Roth et al. (1997), and applied within a different theoretical frame of reference by McRobbie et al. (2001), confirms the outcomes of Welch's (1999) mapping study and the earlier studies of primary students' design activity undertaken by Jones and Carr (1993) and Kimbell et al. (1996). In this study, the maps, like Welch's, highlighted the importance of three-dimensional modelling and the lack of fit of pre-designed step-by-step models for considering how design processes are engaged in during design and make tasks.

This initial fine grained analysis of the study described in this paper goes some way to providing insights into the different approaches taken by groups as they solved problems on different levels and why they tackled the problems in the ways they did. The mapping of the design processes revealed the different approaches taken by the student groups, all moving towards the achievement of success in the development of their final products, but taking different paths as they responded to the materials, tools, their own background knowledge, skills, abilities and prior experiences, and to each other and the tasks at hand. An important outcome revealed by the maps was that there was random trial and error behaviour displayed by the groups supplemented by limited action that was the result of logical conclusions and predictions from the perspectives of those involved, and comprising reasoned generate-and-test procedures. The mapping of the various move experiments and their linkages amongst them confirm the view that design processes involve a complex interplay between and amongst tools, resources, ideas and people (Roth, 1998) resulting in the co-generation of ideas (Roth, 2001), as designers engage in see-move-see again processes (Schön & Wiggins, 1992).

The nature of the learning tasks, as open-ended projects set within some teacher-set structure to guide action and decision making, played a large part in developing the students' enthusiasm for achieving success in their final products and for them viewing the activity as authentic (McCormick, 1994; Stein, et al., 2001). In turn, this mix of open-endedness, support and authenticity, promoted the development of the students' own vision for their final products which was tempered by the parameters of time and resources. The maps show that most of the learning took place in the area of design processes. Using Faulkner's (1994) typology, the students were immersed in activities which assisted them to experience, in some instances become aware explicitly, of design practice (aspects of design criteria, design competence and instrumentalities, practical considerations, and developing and testing procedures), but little explicit knowledge was developed about the natural world, that is, knowledge about the properties of materials, and scientific and engineering knowledge related to tasks at hand.

This study thus raises issues related to the teaching and learning of technology processes and concepts and the role played by teachers in assisting students to become explicitly aware of technological concepts and processes. As already stated, the nature of the project described in this paper stimulated the students to some degree to think about the design processes in which they were engaged. Furthermore, while they were aware of the need to know more about materials, for example, or the need to be able to use certain tools, the evidence did not support the notion that the students had developed specific and explicit knowledge about tools or about the properties of materials. The students' knowledge remained, essentially, within the realms of the artefacts with which they were working, and it did not move to a level of world knowledge or knowledge of the natural world (Faulkner, 1994; Roth, 1998). In the light of Crismond's (2001) findings, it would appear, that perhaps our observations were commonplace among non-expert designers: that there is need for overt teacher intervention to encourage students to recognise knowledge development.

The challenge for teachers lies in finding balance between (a) creating tasks that allow students to find authenticity and meaning, and (b) intervening, to assist students to recognise the world knowledge meaning of their encounters and experiences. The individuals within the groups described in this study could not necessarily have predicted the problems that were to arise with the materials and tools they had to use. The need for one group to be able to incorporate a motor into the vehicle, for example, only arose out of the context within which that group was involved. Furthermore, that group was not faced with the task of incorporating "any" motor into "any" vehicle. It was because the group members used the styrofoam as their vehicle body, had particular wheels, axles, elastic bands and motor (because these were the resources that were readily available to them) that their problems arose. The situation in which they found themselves was a result of particular events and circumstances of that particular situation. The situation could not necessarily have been predicted within the context of an open-ended project such as the one described, but it could have been seen as a possibility.

Learning can be described as "a change in the learner's capability of experiencing a phenomenon in the world" (Marton & Pang, 1999, p. 11). To develop that capability, it is necessary for teachers to provide opportunities for learners to experience a wide variety of instances and phenomena in many different ways. As a consequence, learners' awareness of and sensitivity to aspects of phenomena (brought into the foreground or sent to the background of attention) are raised and made explicit (Marton & Pang, 1999). Thus, there is an implication for teaching. In order to capture the learning moment, it is vital for the teachers to be alert to the problems and questions being experienced by students at the time when they are most relevant. It is also important for teachers to be aware of the possibilities of situations of significance for learning that may occur. In this way, opportunities for helping students to develop explicit knowledge about the natural world can be capitalised upon. An open-ended, loosely defined project can create an environment for authentic experience and present opportunities for a wide variety of instances and phenomena in many different ways to be experienced. However, without intervention by the teacher at appropriate times, deeper and more extensive learning about the natural world, about design and technology concepts and processes will not necessarily occur. In other words, learners often need assistance to develop knowledge of which aspects of instances and phenomena to focus upon (and, therefore, learn more about) and which aspects are of less significance. Planned interactions with students as part of unplanned (but, perhaps, predictable) situations or encounters with materials, artefacts and tools, are therefore important times during which students' learning can be scaffolded, supported and developed. These opportunities help students develop breadth of (explicit) technological knowledge and experience. Without breadth, depth and variety of experience within different contexts, ability to differentiate between and amongst phenomena will not necessarily occur (Marton & Pang, 1999).

Conclusion

In the detail about design processes provided by analysing the Year 6 group projects in the way we have, mapping the participants' actions and decisions throughout the course of an open-ended, loosely defined design and make project, we have shown that: the interactions amongst the novice designers and the materials and tools at hand are significant elements that work together in a complex intertwining and interlinking relationship; and that from an educational point of view, open ended and loosely defined tasks help create opportunities that allow learners to discover for themselves what they need to learn to solve design and make problems. These problems were made real because they emerged from the task that the learners set themselves as they worked towards achieving their own goals for success. However, we have also highlighted the need for teacher intervention during the design activity to help students focus upon what is important in terms of design and technology concepts and processes. Without that intervention, students will not necessarily develop their understandings.

We began this study with the belief that, if teachers are to assist students to enhance their design processes, it is important that we first find out the detailed nature of the design processes that students are actually using, rather than assume theoretical or empirical models derived from professional designers' actions. The maps produced in this study go some way to continuing the analyses begun by more coarse grained studies into the design processes used by primary school novice designers. This study has produced understandings about design processes on a fine grained level, which may be useful for assisting the continuing exploration of the designing activities of younger novice designers. The understandings gained through this study have the potential to inform pre-service and in-service teacher education courses on design technology to enhance the competence and confidence of teachers, and to result in improved learning outcomes for students.

Appendix 1 - Mapping Notation (McRobbie, et al. 2001)

Symbol	Meaning	Examples from action/talk
	MACRO PROBLEM • overall problem/task statement, definition, discussion MESO PROBLEM • "large" tasks/problems identified, stated, defined, arising - solving of which contribute to achievement of MACRO problem/task satisfaction MICRO PROBLEM • "small" tasks/problems identified, stated, defined, arising - solving of which contribute to the achievement of MESO problem/task satisfaction • often related to detailed and specific aspects of problem/task e.g., tool or skill related	• stated intentions • clarification of goal • statement of problem to be solved • "We have to do this, don't we?" • "This is what we have to do."
	• *seeing that* • report, observation • literal seeing	• "I observe this (idea) about the physical phenomenon." • "The paddlewheel is not even touching the ground [desk]."
	• *seeing as* • envisioning • a mental action • proposal of idea, construct etc • particular elements of the configuration or formation are perceived/identified/judged to be important or significant to solving the problem	• "Maybe this is something we could try." • "We need something bigger to act as spacers."
	• *seeing as* • envisioning in conjunction with physical	• "This could be how we will do it."

	action • proposal or idea to be translated into material action • particular elements perceived to be important to solving the problem are changed or developed in physical form • proposal is a translation/transformation of mental action and physical phenomena	• "We could cut a circle out of sheet metal, put like a really thin piece of wood in the middle and stick them together to make them stronger."
	• *seeing in* • as above (physical phenomena plus mental activity - envisioning) but with a conclusion • proposal or idea translated into material action • conceptualisation of how something works/happens • extended mental component • attempt to explain at operational or abstract principle levels	• "This is how it works." • "This is what is happening when it works." • Everything has been put together in one's own mind. • "The beams across the corners are conferring stability and thus are holding the frame together." • "These beams are examples of (the technological principle of) bracing with a triangular structure." • "Now we need to get a straw to put that round so that way the wheels can move inside the straw and the sticky tape doesn't prevent the axle from turning."

Appendix 2 - Connectors (McRobbie, et al. 2001)

Symbol	Meaning	Examples from action/talk
	• link between move experiments • contributing actions • sideline actions • indicates learning about the problem, the tools, the solution, the resources etc	• off on a tangent • something from out of the blue • a group member's suggestion or identification of a possibility
	• link between move experiments • actions that contribute to "moving on" • indicates learning about the problem, the tools, the solution, the resources etc	• this move experiment *is leading to* this move experiment
	• link between move experiments • tentative connections/contributions • indicates learning about the problem, the tools, the solution, the resources etc	• this *could be* or *seems to be* emanating from this move experiment
	• link between move experiments • links back/forward to actions/questions/ideas from another part of the map	• this solves the problem left unsolved earlier in the course of events • this is the same problem arising once more even though action has taken another course in the time being • the problem arises again in another form

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Figure 1: The macro, meso and micro problems encountered by Group 2 across the period of the second part of the unit of work.

Figure 2: The macro, meso and micro problems encountered by Group 1 across the period of the second part of the unit of work.

Figure 3: Group 1's efforts to develop part of the paddlewheel.

Figure 4: Group 2 showed an implicit understanding of the role played by the straw in the wheel and axle assembly.