Elementary School Students' Understandings of Technology Concepts

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Elementary school teachers and teacher educators have expressed concerns about what students learn as they engage in design and technology activities. This study was designed to identify students' understandings of selected technology concepts, and changes in those understandings across a range of age levels corresponding to grades 2, 4 and 6 at elementary school. Following an extensive interview program and subsequent data analysis, it is argued that commonalities and variations in understandings exist within and across age levels. The identification of these commonalities and variations is examined for their implications for classroom teachers, the development of more appropriate design and technology programs, and preservice and inservice teacher education.

Background

A framework for the development of design and technology curricula by the various states in Australia has been established in two documents—a national statement and a national profile in Technology Education (Curriculum Corporation, 1994a, b). Technology has been defined as involving "the purposeful application of knowledge, experience and resources to create products and processes that meet human needs" (Curriculum Corporation, 1994a, p. 3). This framework, in common with other international and national statements (e.g., American Association for the Advancement of Science (AAAS), 1993) and curriculum documents (e.g., Queensland Schools Curriculum Council (QSCC), 2000), stressed the importance of providing students with opportunities for participation in meaningful learning experiences in which they could draw upon their existing knowledge of materials, tools, machines, and systems, as well as gather and use information from a variety of sources. Further, the framework indicates that the meaningful learning experiences should facilitate the engagement of students in problem solving to produce an end process, product, or artifact, thus enabling their construction of new and deeper understandings of design and technology concepts and processes. The intentions of the framework were linked with outcome statements that reflected the

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attainment by students of a range of problem solving skills, manipulative skills, and, in particular, understandings of design and technology concepts.

A relatively small amount of research has been done on students' understandings of design and technology concepts, or technical knowledge (Bennett, 1996; Gustafson, Rowell, & Rose, 1998; Levinson, Murphy, & McCormick, 1997; Twyford & Järvinen, 2000). This limited research base represents a constraint for teachers, teacher educators, and curriculum developers who wish to capitalize on the rich and varied content of technology. Clearly, more research in this area is needed to support effective implementation of technology programs and enhance the preservice and inservice training of teachers.

It may be difficult to define what is concept knowledge in design and technology because of the amount of personal knowledge used at various stages in the design process (McCormick, 1997). A perception also exists that design and technology is underpinned by science-related concepts and, consequently, science education research may already provide some information about concepts in design and technology (Gustafson et al., 1998). However, we argue there are concepts that relate identifiably to design and technology that may already have been explored in science education research, but not in technological settings. For example, although science education researchers have probed students' understandings of the nature and behavior of matter (Kruel, Watson, & Glazar, 1998), we are unaware of research into students' understandings of properties of matter, which should be kept in mind when choosing materials to construct an artifact. Technologists may have to take into account one or more properties of materials, such as strength, flexibility, conductivity, and durability, or so-called "functional" properties (Cajas, 2001), when deciding which material to use for the production of an artifact. Consequently, trade-offs between various properties become an important component of selection and decision-making processes. A useful insight from science education research that can inform investigations into students' understandings of materials in technological settings is that young students tend to link their concept of matter to tangible properties such as weight or heaviness (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Smith, Carey, & Wiser, 1985).

Gustafson et al. (1998) reported grade 3, 4 and 5 students' understandings of elements that contributed to the structural stability of towers, including ideas such as adding a heavy base, adding feet to supports, thickening supports, and reinforcing joints. The strength of materials from which towers are constructed, as well as the design of bracing, are also elements that contribute to the stability of towers. Ideally, students should be able to understand the complex relationships between knowledge of the properties of materials, stability, and bracing during the construction of worthwhile artifacts, or the achievement of quality solutions (National Association of Advisers and Inspectors in Design and Technology, 1994).

Because material properties (e.g., strength), stability, and bracing are important in many technological settings and activities, we contend that an understanding of these concepts should be part of an identifiable knowledge base for students, as well as teachers of design and technology in elementary school. Jones, Moreland, and Chambers (2001) asserted that the notion of a technology knowledge base for teachers is pivotal for effective teaching and assessment in technology education. Their study included the development of a planning format for teachers that assisted in the identification of specific concepts required by teachers in different technology areas. Likewise, the importance of conceptual knowledge, particularly in its relationship to procedural knowledge, has also been emphasized (McCormick, 1997). In addition, Lewis (1999) asserted that an understanding of the technology concepts students possess is an important prerequisite for better teaching.

When confronting the issue of a limited research base on students' understandings of design and technology concepts, it is useful to draw upon the methods and techniques used in science education research that have led to the development of a large quantity of research findings about students' understandings of fundamental science concepts. These research findings have contributed significantly to learning theories and practice in science (e.g., Yager, 1991), curriculum development and implementation in science (Driver, Leach, Scott, & Wood-Robinson, 1994), and preservice and inservice teacher education.

Driver et al. (1994), in their review of research on the understandings of science concepts of students in the age range 5-16 years, proposed that "learning within a particular domain can be characterized in terms of progress through a sequence of conceptualizations which portray significant steps in the way knowledge within the given domain is represented" (p. 85). They used the phrase "conceptual trajectory" to label this sequence of the most frequent conceptualizations at different age levels, the trajectory being evident in the progression towards more scientifically acceptable views of the relevant concept. Further, the conceptualizations are indicative of possible groupings or categorizations of explanations of phenomena. To illustrate such a trajectory, the most frequent conceptualization of the youngest students is that air exists only as "wind" or "breeze." The notion of air as a material substance is the most frequent conceptualization of older students around the mid-point of the age range, followed by a general recognition in the oldest students that air is not only a material substance but has mass as well. Driver et al. claimed that such conceptual trajectories have important implications for curriculum decision-making within the relevant science knowledge domain.

We suggest that cross age studies of students' understandings of technology concepts using methods and techniques similar to those employed in science education research are warranted. If age-related conceptualizations exist in design and technology, and there appears to be a progression to more abstract conceptualizations with increasing age, the findings could be used to inform curriculum development, and to enhance preservice and inservice teacher education programs. Further, practicing teachers, in particular, would be the main beneficiaries of such information because of its direct application to the planning and implementation of technology teaching and learning experiences, and to the assessment of students' learning.

Students' understandings of selected technology concepts, and changes in those understandings, across the age range 6-13 years were investigated in this study. The paper reports the findings related to the concept of strength of materials and the concept of stability, and analyzes the commonalities and variations in understandings of those concepts across the age range. The implications of the findings for the development of design and technology programs in the elementary school curriculum, and in preservice and inservice teacher education will be examined.

Methodology

The research methods adopted involved the use of interviews-about-instances (Osborne & Freyberg, 1985). This technique involves presenting a student with artifacts or pictures to explore concepts that he/she associates with a particular label. The common elements and idiosyncrasies of students' ideas are identified from transcript analysis. This methodology has been used to identify students' understandings of a wide range of fundamental science concepts such as material properties (Dickinson, 1987), change of state (Stavy, 1990), properties of air and gases (Benson, Wittrock, & Baur, 1993), and earth and gravity (Vosniadou & Brewer, 1992).

Participants

A total of 92 participants, maintaining approximate gender balance, were drawn from each of three separate year levels in each of six randomly selected elementary schools. The samples of students were drawn from grade 2 (n=27), grade 4 (n=37), and grade 6 (n=28), which spanned the age range 6 to 13 years. All participants were interviewed using the interview-about-instances approach. Data were collected over a three-month period.

In preliminary discussions among the authors, an interview protocol was developed, which was trialed with the first ten interviewees. Minor modifications were made before proceeding with the remainder of the interviews. All students were interviewed individually by one author (RSD). The interviews lasted from 15 minutes for the younger year levels to 20-25 minutes for the older students and were conducted in a withdrawal room adjacent to the relevant classroom. Students were selected by their teachers as being representative of students in their respective classes. No demographic data were collected from the students except age and gender.

In the interviews, each participant was presented with a series of models and pictures of objects that the student might associate with a label—examples of bridges, bicycles, and carry bags were used. Questions designed to probe the student's understandings of materials and stability followed a general framework for guidance as shown below:

- *Tell me as much as you can about this object, what it is, how it is made, and what it is made out of. (At the same time students were shown an artifact such as a model bridge constructed out of wood.)*
- *If you were building this bridge [type] to carry cars and/or pedestrians, what material(s) would you build it out of and why?*
- *Is this bridge stable? If not, explain how you would make it more stable.*
- *How do the changes you have suggested make the bridge more stable?*

The students were asked these questions in a manner that was responsive to their age and language ability. The students were not probed further for their sources of information but in some cases prior experiences did seem to inform their explanations.

The open-ended questions were intended to focus students' attention on a model and/or pictures of an artifact. The model bridge utilized in the interviews was a truss bridge, approximately 40 cm in length and 25 cm height, and constructed of lengths of wooden dowels. The dowels were joined with small nut and bolt fasteners; twine was used to attach cross members to form part of the deck of the bridge. The deck was completed using a strip of high-density rubber, which was not fastened to any part of the structure. interviews were audiotaped for coding and analysis. Preliminary interviews revealed more constructive talk was elicited from the students using the bridge and associated pictures than was the case with other sample artifacts. Hence, for the purposes of this paper, only the findings relating to students' responses to the questions about the model bridge will be reported.

Analysis of Data

The analysis of explanations was undertaken through an ongoing examination of data after each set of interviews was completed. For example, the students' responses to the open-ended questions, such as the second example question above, were examined for the understandings evident in their explanations. The range and kinds of explanations were also noted. Explanations that were based on a similar object or idea were grouped together. This grouping of explanations is similar to the possible grouping or categorization of explanations of phenomena that comprised Driver et al.'s (1994) work on most frequent conceptualizations at different age levels, and conceptual trajectories. Disagreements on assigning explanations to a particular group were resolved by further discussion until a consensus was reached. The final analysis of explanations involved a review of the students' explanations and the assignment of these explanations to relevant groups. From the total body of data, groups of explanations for the three age levels included in the study were derived, and progression in terms of increasing abstractness of the groupings was noted.

Findings

Insights into students' understandings of the selected technology concepts are presented in this section. Exemplars of grade 2, grade 4, and grade 6 students' responses to relevant questions are used to illustrate some of the commonalities and variations in their explanations and how the groups were derived. All names used in the discussion are pseudonyms.

Materials and Material Properties

Initially, all students were asked to tell the interviewer as much as they could about the model bridge. Most students recognized the artifact as a bridge and continued on to identify and describe the materials used in its construction. Three students (two grade 2, one grade 6) had to be told what the object was.

Commonalities were noted in the students' explanations when they were presented with the scenario of building a bridge on a larger scale to carry cars or pedestrians and were asked to describe and justify what changes would be necessary to achieve this. One commonality was the suggestion by most students that the bridge would have to be built out of a material (or combination of materials) that was stronger than the wood from which the model bridge was built. The property of strength was referred to directly by the students and/or could be inferred from the justifications provided by the students for the use of different materials, as evident in the following extracts from interviews (I = interviewer; R = respondent).

I: What are we going to build (the bridge) out of?
R: Steel.
I: Why?
R: Cuz, wood's not strong enough to hold a car. (Peter, grade 2)

I: (after discussing certain changes suggested) So, you wouldn't make it out of wood?
R: (laughs) No.
I: Why not?
R: Cuz, cars could . . . like the bridge would collapse if it was made of wood. (Tahnee, grade 4)

I: What would you change (about the bridge)?
R: This bit bigger and the wood a bit thicker. Made out of steel.
I: Thick wood or steel or both?
R: Make it out of steel.
I: Why?
R: It's heavier and you can't really bend it. (Denice, grade 6)

While the material property of strength could be described as one commonality noted across all age levels in the study, variations were observed in the students' explanations for material strength. One variation could be described as a naïve explanation, indicative of a limited understanding of material properties (e.g., Sharon – grade 2).

I: What's so good about steel?
R: Because it doesn't break.
I: Why doesn't steel break?
R: Because it's made out of plastic and it doesn't break.

Denice's explanation noted earlier, demonstrates another variation, that of equating strength of material with heaviness, or weight. Similarly, Erica (Year 4), in the following exchange equated strength with heaviness and also attempted to describe the composition of the metal.

I: Why?
R: Because it's stronger.
I: I wonder why metal's stronger. What is it about metal that makes it stronger?
R: Because metal is heavier and it's just made out of heavy—really heavy stuff.

Students' explanations that referred to the hardness of metal and concrete/cement represent another variation noted. Helen (grade 2), when asked why metal was stronger, replied that "if you get thin bits of wood you can snap them but you can't metal." In this explanation she linked strength and the breakability of materials, and compared the respective properties of wood and metal. Helen could have drawn from personal experience for this explanation.

Even though the explanations provided by Denice, Erica, and Helen varied, we grouped these explanations together because the students attempted to articulate their understanding of the strength of the material out of which they believed the stronger bridge should be constructed. They did not refer solely to the lack of strength of wood as a basis for their justification, hence this group of explanations has been labeled as *Non-artifact related*. Other groups of explanations of material strength that emerged from the data were *Naïve*, *Artifact related*, and *Particle related*.

Each student's explanation was analyzed and assigned to a relevant group of explanations. The percent frequencies of students' explanations in each group are shown in Table 1 by age level. The order of these groups, from left to right in the table, is, arguably, representative of increasingly abstract explanations. In the case where a student's explanation appeared to be linked to two different groups, the explanation was assigned to the more abstract of the two.

Table 1
Percentage Frequencies of Types of Explanations with Age – Material Strength[#]

Grade level	Naïve[1] (%)	Artifact related[2] (%)	Non-artifact related[3] (%)	Particle related[4] (%)
Grade 2	11.1	81.5	7.4	0.0
Grade 4	0.0	81.1	16.2	2.7
Grade 6	0.0	46.4	46.4	7.1

[1] Inappropriate explanation in relation to material properties; [2] Explanation associated specifically with presented artifact; [3] Explanation associated with physical properties of material chosen by student; [4]Explanation indicative of some formal, though limited scientifically acceptable understanding.
[#] Variations from 100% due to rounding.

Examples of explanations from each of the groups will now be presented and described. Firstly, three grade 2 students appeared to be able to identify materials but were unable to discriminate between the properties of different materials. Sharon's explanation has already been described, and a second instance is presented in the following extract from the interview with Melanie (Year 2).

I: If we made this bridge out of metal, would it be a strong bridge?
R: Yes, because metal's like timber.
I: How is it like timber?
R: Because they're both made with metal and stuff, and timber's a little bit stronger than metal.

Clearly, both Melanie and Sharon need to develop understandings that will enable them to discern that different materials have different properties. We have labeled this group *Naïve* as they have inappropriately connected the properties of two dissimilar materials when talking about material strength.

A second group was evident in the students' explanations for choosing steel (or metal) in terms of the lack of strength of the wood used in the construction of the model bridge. The majority of grade 2 students (e.g., Peter) and grade 4 students (e.g., Tahnee) recognized that a material such as steel was suitable for the construction of a stronger bridge, but then referred to the lack of strength of wood when attempting to explain their decision. We can infer that they were able to discriminate between the strength of steel (or metal) and the strength of wood and make judgments about the suitability of each material for the construction of strong bridges. However, the basis of their response was the presented artifact. Hence, we have identified this group of explanations as *Artifact related*.

The third group, *Non-artifact related*, was evident in students' selection of the material and the justification of their selection based on a property of the material itself. Denice's justification for using steel because it was heavy and does not easily bend was mentioned earlier. Similarly, Trevor was able to describe the characteristics of the metal he would use to build a strong bridge and elaborated on how that metal might become less strong over time.

I: What are the characteristics of metal?
R: It doesn't crack when you, like, use it on something, it's a lot tougher.
I: What do you mean by tougher?
R: It doesn't break as easy. You have to cut it to break it, unless it's rusty.
I: What do you mean by rusty?
R: Corrodes it away and makes metal soft.

Two grade 6 students were able to extend their justification of the material selected based on a property of the material itself, into a consideration of the particulate nature of the material. For example, Mary provided an explanation based on the material she selected for building a stronger bridge (concrete), and then elaborated by talking about molecules being present in concrete, when questioned further.

I: You said concrete. Why would that be a better material?
R: Because if you had a fire it would not burn down. And it'd be a lot stronger. And you can't bend it or anything.
I: What is it about concrete that makes it stronger than wood?
R: Um . . . it just is.
I: You said it (concrete) doesn't bend.
R: Because it sets really hard because it has all these molecules and stuff in it that makes it set really hard.
I: What do you mean by molecules? What's happening? What's your understanding of that?
R: Particles and stuff that join up and make it hard.
I: Could I see these if I cut it in half?
R: No.
I: Why not?
R: 'Cause they're too tiny.
I: So it's these tiny little things that are making it strong? Well how's that different to wood? Because wood would be made up of these tiny things as well wouldn't it?
R: Yeah.
I: So why isn't wood as strong as concrete?
R: I don't know. Because . . . you have to . . . it's kind of hard to explain. It's just the way it is.

It is acknowledged that this interpretation may be challenged on the basis that Mary's explanation is not canonical science, and that she may not have been able to sustain the explanation under further questioning. We argue, however, that at the very least her explanation may indicate an awareness of the inadequacies of prior explanations and a need to seek a more formal understanding. An interesting feature of Mary's case is that her initial explanations could be deemed as being *Non-artifact related*. Further probing provided her with the opportunity to articulate a more abstract explanation, hence, the fourth group, *Particle related*, was formed to accommodate such explanations.

Trends are evident in the percentage frequencies of groups shown in Table 1. The frequencies of *Naïve* explanations and *Artifact related* explanations decrease with age, although the differences in percentage frequency from grade 2 to grade 4 for the latter are small. On the other hand, percentage frequencies of *Non-artifact related* explanations and *Particle related* explanations increase with age.

Explanations that refer to the presented artifact (*Artifact related*) are the most frequent for grade 2 (81.5%) and grade 4 (81.1%) students. Explanations that refer to the presented artifact (*Artifact related)* and the students' material of choice (*Non-artifact related)* are the most frequent explanations for grade 6 students (46.4% respectively). This consideration of most frequent explanations at different age levels is similar to Driver et al.'s (1994) conceptual trajectory discussed previously. From this analysis, we suggest that there was a change in the way students conceived the problem represented in the stimulus question, thus many grade 6 students were able to provide explanations that went beyond the perceived limits of the presented artifact.

Stability

Commonalities were found in students' explanations when asked how they would make the bridge more stable. Typically, the explanations referred to a way of, or approach to, solving the problem; for example, the use of a binding material, usually cement or concrete, to stabilize the pylons of the bridge, as illustrated in the following extracts from interviews.

R: I would get some cement, put one there, put one there, put one there, put one there.
I: Around each of the four feet you'd put some cement?
R: Yeah, and then it would like stay still (Peter, grade 2)

R: Cement it into the ground.
I: How would you do that?
R: It's like, dig a hole and put it in, and put cement around it (Sarah, grade 4)

Explanations of this kind occurred in a sufficient number of interviews to suggest that students may view fixing of structures into a binding material, such as concrete, as a way of improving the stability of many structures with features similar to the bridge. It would seem that the students were familiar with this approach to solving the problem, perhaps from personal experiences, conceptualizing the approach as the cement binding to the pylons of the bridge, which then "holds it tight." The effect may be seen as analogous to the action of glue binding two materials together, although an important difference is that the cement or concrete is heavy, and thus "holds it better," especially if adverse weather conditions are experienced. As Mary (grade 6) stated, "It's just more firm and it just . . . stays. It's like really heavy and it just stays there."

A variation of this idea was to screw or bolt the structure into the ground. It can be argued that this approach may have a similar conceptual basis to concreting/cementing, in that it sticks or "holds tight" the structure to the ground. The approach was often seen as being used in conjunction with concrete/cement, which supplied the necessary weight for stabilizing the bridge.

Five groups of explanations for how to make the bridge more stable emerged from the data and were labeled as *Naïve Approach, Base Anchoring Approach, Bracing (External) Approach, Bracing (Internal) Approach,* or *Other Approach* for students whose explanations were unable to be classified in any of the former. The labels for these groups represent the bases for the grouping of explanations, similar to the previous discussion for material strength. The percentage frequencies of the groups are shown in Table 2 by age level. The order of the groups, from left to right in the table, is argued, tentatively, to be representative of increasingly abstract explanations that are more complex/multiple approaches to solving the problem. Where a student's explanation was linked to two different groups, the explanation has been assigned to the more abstract group.

A *Naive approach* for making the bridge more stable may be found in Sandy's (grade 2) explanation.

I: How would I stop (the bridge) from wobbling?
R: Keep hammering in the nails until it doesn't wobble.

Table 2
Percent Frequencies of Types of Explanations with Age – Stability[#]

Year level	Naive Approach (%)	Base Anchoring Approach (%)	Bracing (External) Approach (%)	Bracing (Internal) Approach (%)	Other Approach (%)
Year 2	18.5	48.1	18.5	11.1	3.7
Year 4	5.4	46.0	37.8	5.4	5.4
Year 6	3.6	17.9	57.1	21.4	0.0

[#] Variations from 100% due to rounding.

The most common approach to this problem was, as already discussed, to place the pylons of the bridge into cement or concrete (*Base Anchoring Approach*).

Explanations that referred to the addition of an external support of some kind to stabilize the structure (e.g., external bracing or pylons) were categorized into the *Bracing (External) Approach* group. Suggested additions were external to the existing structure of the bridge and, thus, of a quite different nature to internal structural bracing. An example of this approach may be seen in Jenny's (grade 6) explanation below.

I: Is there anything we can do to improve stability?
R: Maybe you could put little things down here.
I: So, extra little legs coming down from the middle?
R: Yes, and maybe put these in cement so they won't move.

Jenny's explanation also refers to the placement of added pylons in cement in her response. Her explanation may be linked to two different groups but has been assigned to the more abstract grouping (*Bracing [External] Approach*). Some students proposed adding to the existing internal structural bracing present in the bridge (*Bracing (Internal) Approach*). Kate (grade 6), for example, when asked what changes she would make to the bridge, replied that "You might have to put more smaller triangles into these bigger ones so it's more stable."

Three students suggested solutions that implied the pylons of the bridge needed 'evening up' and were grouped as *Other* for inclusion in the table. There are clear trends in the group frequencies for explanations of stability presented in Table 2. The percent frequencies of *Naive Approach* and *Base Anchoring Approach* explanations decrease with age while the percent frequency of *Bracing (External) Approach* explanations increases with age. The results for *Bracing (Internal) Approach* do not reveal an age-related trend, which may be due, in part, to the small numbers at each age level providing such explanations. Explanations that refer to the *Base Anchoring Approach* are the most frequent for grade 2 (48.1%) and grade 4 (46.0%) students, and explanations that refer to a *Bracing [External] Approach* are the most frequent for grade 6 (57.1%) students. Based on these findings related to most frequent explanations at different age levels, we suggest that there was a change in the way students conceptualized an approach to solving the problem of stabilizing the bridge. We also suggest that adding external support to the bridge (*Bracing [External] Approach)* is a more complex, or abstract, approach than the relatively simple approach of concreting the end pylons of the bridge into the ground (*Base Anchoring Approach)*.

Discussion

The majority of students in each grade level were able to identify a material that they believed would be suitable to build a bridge on a larger scale to carry cars or pedestrians. The property of the material to which they referred, either directly or indirectly, was strength. When asked to explain their understanding of this property, students in each of the age levels often resorted to describing strength in terms of more tangible properties, such as malleability or weight.

The explanations of three grade 2 students revealed their uncertainty about material properties and how the properties of one substance would differ from other substances, for example, plastic and wood. Explanations of this kind were grouped as *Naïve* because of the students' inability to discriminate between the properties of different materials.

A second grouping (*Artifact related*) resulted from students' attempts to explain why they selected steel (or metal) for the larger bridge, but referred to the lack of strength of wood in their explanations. Arguably, if some of the students possessed an understanding of matter that involved a relationship between the type of matter and weight, a relationship noted in the science education literature (Smith, Carey, & Wiser, 1985), they might have associated the relative lightness of wood with lack of strength compared to steel. They may have seen that relationship as a reason for describing why wood should not be used, rather than being able to provide a justification that involved elaborating on a property of steel or metal. The explanations could be described as being *Artifact related* since they appear to be dependent on the nature of the material out of which the presented object is constructed.

The third group of explanations noted (*Non-artifact related*) was the students' justification for their choice of steel on the basis of a property of steel itself. The students (mainly grade 6) providing these explanations were able to think of, and evaluate, their choice of material unencumbered by the presence of a model bridge constructed out of wood at hand. Therefore, their explanations were not limited to the artifact but generalizable to other settings. Further, there was evidence that a small number of students were beginning to consider the particulate nature of materials as a way of justifying their selections of steel or concrete for the larger bridge, although it is acknowledged that such understanding was clearly emergent in nature and not fully developed.

Identifiable groups of explanations may also exist for students' understandings of stability. Gustafson et al. (1998) refer to students' ideas for making a straw tower more stable—adding a heavy base, adding feet to supports, thickening supports, adding bracing, and reinforcing joints. Although no details in their paper were provided that related the nature of the idea with age of students, there are some similarities with our findings. For example, many students in this study suggested that cementing the pylons into the ground (*Base Anchoring Approach*) could stabilize the bridge. This solution may be equated with adding a heavy base as described in the work of Gustafson et al. An increasing number of students across the age levels studied suggested that additional external bracing was required to confer even greater stability to the structure (*Bracing [External] Approach),* and others indicated that internal bracing (*Bracing [Internal] Approach)* should be added. Students' suggestions for the use of external and internal bracing as approaches to solving the problem are also in accord with the findings of Gustafson et al.

Implications and Conclusions

We conclude that there is evidence to support the conjecture that groupings of students' explanations at the different age levels are most frequent for the concept of material strength and the concept of stability. The notion of most frequent groups of explanations at different age levels is embodied in the conceptual trajectories as proposed by Driver et al. (1994). There appears to be a progression toward more abstract common explanations with increasing age for the concept of material strength. A progression in the explanations of stability is similarly apparent, albeit not definitive and relies upon certain anomalous data. The use of the model bridge at the interview may have limited some students to basing their explanations on the material out of which the model was constructed. Consequently, an important task facing researchers is to devise probes into students' understandings of technological concepts that are not linked to any particular artifact or technological process. We recognize that fulfilling such a requirement may prove to be quite challenging. Nonetheless, we suggest that it would address some important issues that have arisen from this study.

An increasing awareness of students' understandings of design and technology concepts can have an impact on the teaching and learning of design and technology in elementary schools similar to that experienced in elementary science education, which has benefited greatly from research into students' understandings of fundamental science concepts. Although more research is needed, the findings imply that commonalities and variations in students' explanations of material strength and stability may exist, and there may be an identifiable progression in the abstractness of the basis of those explanations that is age related. These implications can be taken into account in the future development of preservice and inservice teacher education programs, and the development of more appropriate design and technology curricula. The information can also inform teachers as they plan and implement technology programs, and grapple with making in-depth judgments about students' achievement of outcomes related to technology content and processes.

We consider that it is essential to continue this line of research in order to determine if similar groupings of explanations exist for other key design and technology concepts. Design and technology has a demonstrated potential to contribute to meaningful educational experiences of students. Hence, all elementary school teachers must be better informed about the design and technology concepts students acquire through engagement in technological thinking and activity. This is clearly an important concern, not only from the point of view of classroom teachers, students, and parents, but is also an increasingly important systemic consideration.

References

American Association for the Advancement of Science. (1993*). Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Bennett, R. (1996). An investigation into some Key Stage 2 children's learning of foundation concepts associated with geared mechanisms. *Journal of Design and Technology Education, 1*(3), 218-229.

Benson, D., Wittrock, M., & Baur, M. (1993). Students' preconceptions of the nature of gases. *Journal of Research in Science Teaching, 30*(6), 587-597.

Cajas, F. (2001). The science/technology interaction: Implications for science literacy. *Journal of Research in Science Teaching, 38*(7), 715-729.

Curriculum Corporation. (1994a). *A statement on technology for Australian schools.* Carlton, VIC: Author.

Curriculum Corporation. (1994b). *Technology - A curriculum profile for Australian schools.* Carlton, VIC: Author.

Dickinson, D. (1987). The development of a concept of material kind. *Science Education, 71*(4), 615-628.

Driver, R., Leach, J., Scott, P., & Wood-Robinson, C. (1994). Young people's understanding of science concepts: Implications of cross-age studies for curriculum planning. *Studies in Science Education, 24*, 75-100.

Gustafson, B. J., Rowell. P. M., & Rose, D. P. (1998, April). *Elementary children's conceptions of structural stability: A three year study.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Jones, A., Moreland, J., & Chambers, M. (2001, March). *Enhancing student learning in technology through enhancing teacher technological literacy.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Kruel, D., Watson, R., & Glazar, S. A. (1998). Survey of research related to the development of the concept of 'matter.' *International Journal of Science Education, 20*(3), 257-289.

Lee, O., Eichinger, D. C., Anderson, C. W., Berkheimer, G. D., & Blakeslee, T. D. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching, 30*(3), 249-270.

Levinson, R., Murphy, P., & McCormick, R. (1997). Science and technology concepts in a design and technology project: A pilot study. *Research in Science and Technology Education, 15*(2), 235-255.

Lewis, T. (1999). Research in technology education: Some areas of need. *Journal of Technology Education, 10*(2), 41-56.

McCormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7,* 141-159.

National Association of Advisers and Inspectors in Design and Technology [NAAIDT]. (1994). Quality in design and technology: What should we be looking for? *Design and Technology Teaching, 26*(2), 53-55.

Osborne, R. J., & Freyberg, P. S. (1985). *Learning in science: The implications of children's science.* Auckland: Heinemann.

Queensland School Curriculum Council. (2000). *Technology: Years 1 to 10 syllabus-in-development pilot draft.* Brisbane: Queensland School Curriculum Council.

Smith, C., Carey, S., & Wiser, M. (1985). On differentiation: A case of the development of the concept of size, weight, and density. *Cognition, 21*, 177-237.

Stavy, R. (1990). Children's conception of changes in the state of matter: From liquid (or solid) to gas. *Journal of Research in Science Teaching, 27*(3), 247-266.

Twyford, J., & Järvinen, E-M. (2000). The formation of children's technological concepts: A study of what it means to do technology from a child's perspective. *Journal of Technology Education, 12*(1), 32-48. .

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535-585.

Yager, R. E. (1991). The constructivist learning model: Towards real reform in science education. *The Science Teacher, 58*(September), 52-57.