Elementary Children's Conceptions of Structural Stability: A Three Year Study

Brenda J. Gustafson, Patricia M. Rowell & Dawn P. Rose

Background to the Study

The research reported in this paper is drawn from a much larger three-year study focused on the 1996 implementation of *Problem Solving Through Technology* topics in Alberta, Canada elementary science classrooms. In this three year study, we worked to characterize children's development of technological knowledge and skills during design technology problem solving activities and report on support needed by teachers to present these topics in classrooms. We also examined the *Problem Solving Through Technology* inquiry model presented in the *Alberta Elementary Science Program* (1996) and explored whether this model resembled how professionals (e.g., engineers) engaged in technological problem solving described their work.

The study commenced in September 1995, one year prior to the mandated implementation of a new *Alberta Elementary Science Program* (1996). In this preliminary year (Study Year One), 20 engineers were interviewed about their perceptions of technological problem solving (Rowell, Gustafson & Guilbert, 1997). One hundred fifty three children (80 male, 73 female) completed a performance based assessment related to the impending program. Three hundred thirty four children (180 male, 154 female) completed an *Awareness of Technology Survey*. Data from Study Year One provided insight into children's technological knowledge and problem solving skills prior to formal classroom instruction and information about how engineers characterized their work. In Study Year Two, six case studies were conducted on the classroom implementation of the *Problem Solving Through Technology* topics. These case studies allowed insight into the practical problems encountered by teachers and their concerns about support needed to teach design technology in an effective manner (Rowell & Gustafson, 1998). Case studies also provided a context in which we could begin to characterize how children solved design technology problems in classrooms. Study Year Three involved locating children from Study Year One and re-administering the performance based assessment and a

Brenda J. Gustafson (brenda.gustafson@ualberta.ca) is an Associate Professor in the Department of Elementary Education. Patricia Rowell is a Professor of Elementary Science Education in the Department of Elementary Education. Both are with the University of Alberta, Edmonton, Alberta, Canada. Dawn Rose worked as a Research Assistant in the Department of Elementary Education at the University of Alberta.

revised version of the *Awareness of Technology Survey*. These data showed children's knowledge and skill development after participating in formal classroom instruction in the *Problem Solving Through Technology* topics and allowed for comparisons to Study Year One data.

In the research reported in this paper, we focus on one question from the *Awareness of Technology Survey* which was administered in Study Year One with a revised version of the question presented in Study Year Three. The question, named 'Jane's Tower,' was designed to explore children's awareness of elements which contribute to the stability of a structure. Analysis of the children's responses to this survey question allow discussion of the following two research questions:

1. How do children's perceptions of structural stability change over time?
2. Did the children offer more elegant, quality solutions in Study Year Three?

Elegant solutions were those in which the child offered one simple, useful idea which would allow the tower to be stable. Later in this study, a more thorough definition of elegance is offered and in order to address this question, data were analyzed further with attention paid to children's tendencies to provide a selective or unselective answer.

Related Literature

In recent years, there has been a growing trend towards including design technology in school programs (Layton, 1993). Arguments presented to support this trend include cultural, educational, economic, and political reasons centered on the necessity to develop children's technological capabilities and prepare them to participate in technology-related decision-making. Research on school technology programs has included analysis of the relationship between science and technology (Gardner, Penna, & Brass, 1990 ; Layton, 1993), an exploration of the dimensions of technology (Custer, 1995; Pacey, 1983), an outline of problem solving models (Johnsey, 1995), studies of classroom experiences (Davidson, Murphy, Hennessy, & McCormick 1996; Kimbell, Stables, & Green, 1996; McCormick, Murphy, Hennessy, & Davidson, 1996; Northing, 1989; Roden, 1997), and discussion of the pedagogical implications of design technology (Anning, 1994, 1997; Davies, 1996; Kimbell, Stables, & Green, 1996; Williams & Jinks, 1985).

Implicit within design technology programs is the assumption that children are in need of formal classroom experiences in order to negotiate technology problems and arrive at potential solutions to those problems. Programs, therefore, tend to include information about skills and knowledge that are believed to support technological activity (Alberta Education, 1996; Department of Education and Science, 1985; National Research Council, 1996). In school programs, technological skills such as determining needs, evaluating, planning, and making are frequently arranged into problem solving models which seek to characterize how people solve technological problems (Johnsey, 1995; Layton, 1993). Conceptual knowledge which underpins technological problem solving activities usually appears as concepts, attainment statements, content standards, or knowledge which teachers should assist children to grow towards understanding (Alberta Education, 1996; National Research Council, 1996; Tickle, 1990). Program developers maintain that through developing knowledge and skills, children will become more technologically capable (Kimbell, Stables, & Green, 1996; Layton, 1993).

Much design technology research has focused on characterizing procedural knowledge (skills involved in knowing how to do it) and organizing this knowledge into problem solving models (Johnsey, 1995, 1997; Layton, 1993; McCormick, 1996; McCormick, Hennessy, & Murphy, 1993; McCormick, Murphy, & Hennessy, 1994; Roden, 1997). Researchers have argued that procedural knowledge underpins technological problem solving, might well be context dependent, and is used in combination with conceptual knowledge (understanding relationships among relevant concepts) and strategic knowledge (planning what to do next) to resolve dilemmas which arise during practice (Levinson, Murphy & McCormick, 1997; McCormick, 1996).

It appears that less research has focused on children's conceptual knowledge of design technology (Bennett, 1996; Coenen-Van Den Bergh, 1987; Levinson, Murphy, & McCormick, 1997). This situation is in contrast to science education research which includes an impressive volume of literature on children's conceptual knowledge of science topics and the implications this knowledge has for teaching science (Driver, Guesne, & Tiberghien, 1985; Griffiths, 1994; Osborne & Freyberg, 1985).

This study is based on the assumption that research on children's conceptual knowledge of design technology has implications for curricula and pedagogy. In particular, we explore children's conceptual knowledge of elements that contribute to structural stability. Structural stability, of course, is only one concept which contributes to the production of a purposeful product. Other concepts such as those related to structural strength, joint reinforcement, and material selection represent some areas for future research. Structural stability is frequently associated with designs which include attention to symmetry, a lower center of gravity, an even distribution of weight over base, a stable base, a base broader than the top of the structure, or sinking supports into the ground (Salvadori, 1990). Related to stability are ideas about structural strength, which could contribute to stability. These ideas could include strengthening supports to prevent buckling and reinforcing joints to deter separation. Understanding the nature of children's ideas about structural stability and how these ideas may or may not be influenced through participation in school programs would be useful for both teachers and program developers.

As children use conceptual and other knowledge to solve design technology problems, they should also be encouraged to achieve quality solutions (NAAIDT, 1994). Quality solutions "are effective, efficient and acceptable solutions to perceived needs" which "achieve their purpose with minimum waste of material and energy" (NAAIDT, 1994, p. 54). Such solutions could also be termed elegant or refined and are based on the child's ability to access appropriate knowledge structures, make discerning decisions, and apply ideas. Knowledge needed to achieve quality solutions could, in part, be promoted through practice in which children continuously extend their knowledge and skills in a variety of contexts. In this study, we not only describe the children's conceptual knowledge of structural stability, but also comment on whether children were able to use this knowledge in a discerning, elegant way.

Study Framework

In order to set the context for the research reported in this paper, we begin with a brief description of the Alberta program and then provide information about study instrumentation and data collection.

Alberta Program

In September 1996, a new *Alberta Elementary Science Program* (1996) was mandated for use in Alberta schools. One feature of this program was the inclusion of a *Problem Solving Through Technology* topic at each of the six grade levels. These topics were intended to provide a context in which children could develop technological problem solving capabilities and develop a conceptual understanding of the function and structure of an assortment of devices and structures. Within the revised program, children were asked to design and make structures, boats, aircraft, other vehicles that move, and mechanisms that use electricity.

In Grade One, children participate in a *Building Things* topic that allows them to build models of structures such as buildings, furniture, toys, water wheels and boats. These experiences provide opportunities to explore methods of fastening, joining and shaping materials and the role these methods play in structural stability. Grade Two focuses on the *Buoyancy and Boats* topic in which children are expected to "modify watercraft to increase its stability in water" (Alberta Education, 1996, p. B8), an idea which emphasizes the connection between stability and shape. *Building With a Variety of Materials* is the topic presented in Grade Three in which children construct structures which support objects, span gaps, and serve as containers or buildings. Once again the children practice building techniques which can assist them to understand the link between stability and overall shape and it is likely the children also explore how stability is connected to a stable base, symmetry and weight distribution. Grade Four features a topic entitled *Building Devices and Vehicles That Move*; a topic in which children build stable vehicles through constructing a symmetrical chassis and thinking about the distribution and positioning of weight over that chassis. In Grade Five, children participate in a *Mechanisms Using Electricity* topic in which they design and construct electrical devices such as electrical cars, fans, hoists, and burglar alarms. Some of these building projects would include concepts related to stability. Grade Six features a *Flight* topic in which children build gliders, parachutes, and rockets. These projects help children understand that stability is related to overall shape and weight distribution.

The issue of developing quality solutions for technology problems is also supported in the *Alberta Elementary Science Program* (1996). Children in Grade Three must "understand that simple designs are often as effective as more complex ones, as well as being easier and cheaper to build" (Alberta Education, 1996, p. B14). In Grade Four, a list of product evaluation criteria helps students to develop decision making skills that would support more elegant, refined solutions. These criteria are repeated in Grades Five and Six and most likely would not be excluded from the more modest product evaluation performed in younger grades.

Study Method

Instrument

The instrument used was named the *Awareness of Technology Survey* and featured a selection of questions intended to explore children's ideas about concepts and skills related to the *Alberta Elementary Science Program* (1996). Each of the six grade levels had a different selection of survey questions with some questions being repeated at each grade level if they were judged related to the entire program (e.g., the question about structural stability).

Awareness of Technology Survey questions were either created by the authors or patterned after survey questions posed by a number of other writers (Aikenhead, 1988, Coenen Van Den Bergh, 1987; DES, 1992; Gadd & Morton, 1992 a,b; Harrison & Ryan, 1990; Rennie, 1987; Rennie, Treagust, & Kinnear, 1992; Symington, 1987). Consultations with provincial government personnel familiar with the new elementary science program who had additional experience with developing test items for provincial science achievement exams were used to validate survey items with respect to the new program.

Piloting

Sections of the *Awareness of Technology Survey* were piloted with a group of 140 children in grades one through six (ages 5-12). Grade One children who had yet to develop adequate reading skills had questions read to them as a group; this approach was used despite the fact that the Grade One survey contained little writing. Children's oral questions and advice as well as teacher comments were noted. Written survey responses were analyzed to check whether they addressed the original intent of the questions and, subsequently, revisions were made to wording and format. From this piloting experience, the *Awareness of Technology Survey* was constructed which was used in Study Year One. A revised version of this same survey that asked children to elaborate more on their answers was used in Study Year Three

Selecting the Children and Administering the Survey

The *Awareness of Technology Survey* was administered in cooperation with a rural school system located close to a large urban area. Classrooms were selected by the school system's Program Facilitator who worked to involve children from a variety of schools and grade levels. In Study Year One, 334 children (180 male; 154 female) from all six grade levels completed the survey. In order to assist Grade One children with reading the survey, a research assistant read the survey to each child and assisted with writing down the children's verbal comments. Children in other grades who still might be experiencing reading difficulties were encouraged to ask their teachers for reading assistance

In Study Year Three, 190 children (93 male; 97 female) were located who had participated in Study Year One and a revised version of the *Awareness of Technology Survey* was administered to them. Excluded from Study Year Three data collection were those students who had been enrolled in Grade 6 in Study Year One. Grade 6 students from Study Year One were excluded because in Study Year Two they would have been in Grade Seven (Junior High School) and therefore, would not have participated in classroom experiences related to the design technology topics which were part of the *Alberta Elementary Science Program* (1996). As one of the intentions of re-administering the survey in Study Year Three was to provide feedback on how children's ideas might have changed due to classroom experiences with the design technology topics, it was not useful to include these children.

Study Focus

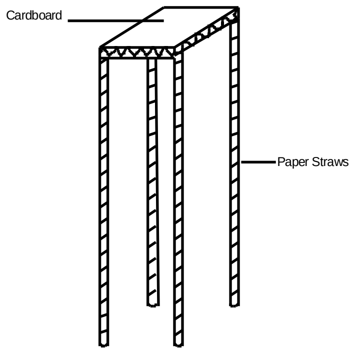
This study will focus on one *Awareness of Technology Survey* question which was administered in Study Year One with a revised version presented in Study Year Three. The question, named 'Jane's Tower,' was designed to explore children's awareness of elements which contribute towards the stability of a structure (see Figures 1 and 2). Results from Study Year One were reported previously (Gustafson & Rowell, 1997, 1998), and attention was drawn to the difficulties experienced by children enrolled in Division I classrooms (Grades 1, 2 and 3) as they tried to provide solutions for the survey question. Children in Division II (Grades 4, 5 and 6) experienced far less difficulty. Therefore, in this study, we focus on 121 children (59 male; 62 female) who were in grades one, two, and three, during Study Year One, who participated in classroom experiences that included exploring structural stability during Study Year Two, and who were in grades three, four, and five during Study Year Three.

Data Analysis

Data analysis began with researchers reading through children's survey responses and collaboratively compiling lists of ideas about structural stability that the children used to answer the question. The complicated and sometimes surprising nature of the children's responses in Study Year One made it necessary to spend considerable time designing and revising these lists, which were subsequently reorganized into coding sheets. Broad categories of 'Ideas Likely to be Useful' and 'Ideas Unlikely to be Useful' were subdivided into the specific ideas offered by the children. Upon generation of coding sheets, a sub-group of randomly selected surveys was independently analyzed by each study researcher, and these were compared to establish reliability among coders.

A single survey response could contain a number of suggestions to prevent Jane's Tower from tipping. For example, one child suggested that a base could be added to the tower (a useful idea), the straw supports could be sunk into the holes drilled in the base (a useful idea), and the base could be made of a heavy material such as wood or metal (a useful idea). This response would fall into three coding categories. Additionally, it would be judged overall as a design which would likely increase the stability of the tower. Other survey responses contained a combination of useful and unlikely to be useful ideas. This type of response could also fall into several coding categories and could be judged as likely or unlikely to be stable overall.

JANE BUILT THIS TOWER USING PAPER STRAWS AND CARDBOARD.



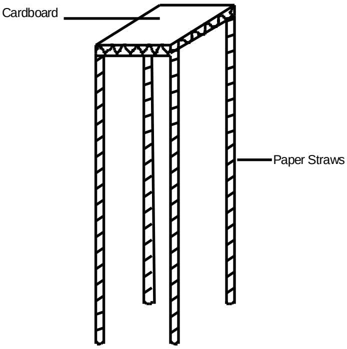
SHE FOUND, HOWEVER, THAT HER TOWER WOULD TIP OVER VERY EASILY. DRAW A PICTURE OF HOW YOU WOULD CHANGE JANE'S TOWER SO THAT IT WOULD NOT TIP OVER. LABEL YOUR PICTURE.

MY TOWER

I CHANGED JANE'S TOWER BY ______________________
____
____
____
____
____

Figure 1. Jane's Tower Survey Question—Study Year One.

JANE BUILT THIS TOWER USING PAPER STRAWS AND CARDBOARD.



SHE FOUND, HOWEVER, THAT HER TOWER WOULD TIP OVER VERY EASILY.

DRAW A PICTURE OF HOW YOU WOULD CHANGE JANE'S TOWER SO THAT IT WOULD NOT TIP OVER. LABEL YOUR PICTURE.

MY TOWER

I CHANGED JANE'S TOWER BY ______________________________________
____
____.

MY TOWER WILL NOT TIP OVER BECAUSE ________________________
____
____.

WHERE DID YOU GET THESE IDEAS ABOUT TIPPING OVER?
____
____
____.

Figure 2. Jane's Tower Survey Question—Study Year Three.

Results

Children's Perceptions of Structural Stability

Prior to formal classroom instruction about structural stability, children at all three grade levels drew and wrote about an impressive array of useful ideas which could increase the stability of Jane's Tower (Gustafson & Rowell, 1997, 1998). Many of these same ideas were repeated in Study Year Three (see Table 1).

The first section of Table 1 shows that some children believed that the addition of a base to Jane's Tower could potentially play a role in stabilizing the tower. Children believed that a stable base could be achieved through adding bases of different sizes and weights; ideas which could contribute towards lowering the center of gravity. Other children added 'feet' to the bottom of the supports that, in effect, broadened the base of the tower. A small number of children suggested sinking the supports into the ground or joining the supports to the desk which resulted in the ground or desk becoming a kind of base.

Ideas related to modifying the supports seemed of particular interest to many of the children. Adding extra straw supports or thickening existing supports could enhance stability while shortening the straw supports would help lower the center of gravity. Some children were concerned with bracing the supports through the addition of internal cross or square bracing or external bracing such as guy lines. Other children were concerned that the supports were made of paper straws; a material they deemed to have insufficient strength to provide adequate stability. These children changed the straw supports to a more substantial material like wood, metal, concrete, cardboard, and brick. We judged these materials to be heavier than paper straws and because of their potential to lower center of gravity they were seen as potentially useful ideas.

Some children suggested modifications to the platform and these ideas could be judged useful or not useful depending on the combination of ideas offered in the survey response. For example, some children widened the platform or changed the platform to a heavier material such as wood, metal, concrete and brick. These heavier materials could enhance stability by creating a downward stabilizing force. To be considered positively, however, this suggestion had to offered in conjunction with suggestions about how supports should be modified to sustain this additional weight. Children who simply suggested a brick platform supported by paper straws were judged to have offered an idea about platform modification which was not useful.

Some children in all grades suggested that existing and new joints could be reinforced with nails, glue, tape, clay, screws or cement. These ideas were judged useful because preventing joints from buckling or giving way could contribute to stability. Other children offered the idea of simply changing the material from which the structure was made to wood, metal, concrete, cardboard, or bricks. This suggestion was judged useful since these heavier materials could increase stability.

Table 1
Children's Ideas About Structural Stability: Study Years One (SY1) and Three (SY3) Comparison

Ideas about Stability	Grade 1 in SY1 (*n*=54)	Grade 3 in SY3 (*n*=54)	Grade 2 in SY1 (*n*=25)	Grade 4 in SY3 (*n*=25)	Grade 3 in SY1 (*n*=42)	Grade 5 in SY3 (*n*=42)
Base addition	3	0	5	2	6	4
Base wider than top	2	8	2	5	7	8
Sinking structure into ground	3	0	0	0	1	0
Joining supports to desk	0	2	1	0	1	1
Adding extra supports	5	5	2	1	4	9
Shortening the supports	4	5	0	2	1	7
Thickening the supports	4	5	0	1	0	1
Bracing the supports (internal)	5	1	6	12	6	10
Bracing the supports (external)	2	4	4	2	6	4
Splaying the supports	2	0	0	1	1	3
Changing support materials	15	13	8	7	18	9
Widening the platform	7	2	1	6	2	3
Changing platform to another material	6	7	4	5	7	1

Table 1 (cont.)
Children's Ideas About Structural Stability: Study Years One (SY1) and Three (SY3) Comparison

Ideas about Stability	Grade 1 in SY1 (*n*=54)	Grade 3 in SY3 (*n*=54)	Grade 2 in SY1 (*n*=25)	Grade 4 in SY3 (*n*=25)	Grade 3 in SY1 (*n*=42)	Grade 5 in SY3 (*n*=42)
Joint reinforcing	3	5	5	0	7	8
Modified entire tower to another material	7	18	1	0	2	3
Not useful ideas	18	6	2	2	5	0

Other design suggestions were judged unlikely to be useful. These ideas tended to be suggested by children in Grade One in Study Year One. They included removing one or two of the supports, moving the supports towards the middle of the platform, building a bigger tower, making the platform heavier while not making modifications to support this increased weight, or simply substituting the materials with light weight plastic. Other children added decorative touches to the platform such as railings, a chimney, a roof, a rooster, cotton balls, and stairs. Some children simply changed the tower to something else (e.g., water tower, barn, silo, lighthouse, temple) making it impossible to judge the way in which they were addressing the stability problems of Jane's Tower. Table 2 shows that the ideas suggested by each child frequently led raters to conclude that Jane's Tower had, in the end, been rendered more stable.

Table 2
Proportion of Children's Towers Likely to be Stable: Study Year One (SY1) Versus Study Year Three (SY3) Comparison

Grade 1 in SY1 (*n*=54)	Grade 3 in SY3 (*n*=54)	Grade 2 in SY1 (*n*=25)	Grade 4 in SY3 (*n*=25)	Grade 3 in SY1 (*n*=42)	Grade 5 in SY3 (*n*=42)
89%	96%	96%	96%	100%	100%

Children's Ability to Achieve Elegant Solutions

Children who achieved a stable tower might have suggested a combination of useful and unlikely to be useful ideas. However, the data show that, in the end, children would quite likely have achieved a stable tower that was judged to be an overall success. An important objective of design technology is to achieve solutions which are "elegant" in nature. A definition of an elegant solution is one in which costs are controlled, time limits are met, criteria are fulfilled, and a solution is reached that is marked by its precision and simplicity (Rowell, Gustafson, & Guilbert, 1997). For Jane's Tower, it would be difficult to judge whether cost and time limits were met. Thus, an alternative definition of an elegant solution for this study was one in which the child offered a single, simple, useful idea that would allow the tower to be stable. This useful idea would not be clouded with ideas unlikely to work or useful ideas that were simply unnecessary. An example of an elegant solution would be a child who wrote simply that the supports should be splayed. This was a solution that was based upon a single, simple idea and it was all that was needed to stabilize the tower.

In Study Year Three, children showed an overall increase in the number of elegant solutions offered (see Table 3).

Table 3
Proportion of Children with Elegant Solutions: Study Year One Versus Study Year Three Comparisons

Grade 1 in SY1 (*n*=54)	Grade 3 in SY3 (*n*=54)	Grade 2 in SY1 (*n*=25)	Grade 4 in SY3 (*n*=25)	Grade 3 in SY1 (*n*=42)	Grade 5 in SY3 (*n*=42)
24%	37%	16%	20%	24%	41%

One might wonder if the students who came up with elegant solutions in Study Year One were the same ones who had elegant solutions on Study Year Three, joined by a few more. Data analysis showed, however, that children who offered elegant solutions in Study Year One were just as likely as other children to offer inelegant solutions in Study Year Three. This observation supports the view that some children were either unable to recognize the value of the elegant solutions offered in Study Year One or had yet to sort through ideas about stability they encountered by Study Year Three.

Discussion

Children in Study Year Three tended to retain useful ideas from Study Year One and mention some of these with a greater frequency than they did in Study Year One. Ideas that were deemed to be less useful appeared with less frequency in Study Year Three. This suggests that life experiences and maturation in the intervening years may have played a role in assisting some children to notice design solutions critical to stability.

An area of interest in Study Year Three concerned the children’s suggestions about materials. Some Study Year One suggestions involved changing the platform to a heavier material while failing to strengthen supports. This combination of ideas would likely lead to the buckling of supports and collapse of the tower. This notion about making the platform out of a heavier material had the potential to be a useful idea, but for some children it was still in need of further refinement. In Study Year Three, some children continued to increase the weight of the platform while paying little attention to support. Assisting children to refine this and other ideas about materials represents a worthwhile focus for further teaching. Opportunities to explore a wide range of materials and the interplay of these materials with each other within a design problem could help children to construct an understanding of the role that context plays in promoting links between conceptual knowledge and procedural knowledge.

It is difficult to draw links between overall trends in children's thinking about useful materials in Study Year One and Study Year Three and the role classroom experiences might have played in this thinking. For example, in Study Year One children mentioned changing tower materials to concrete, metal or wire. In Study Year Three, children continued to mention concrete and metal but no longer subscribed to using wire. Despite this change, it is unlikely in the intervening year that children had any classroom experience building with these materials. Perhaps ideas about materials such as these were based on experiences and observations outside the classroom and the seemingly indiscriminate inclusion and exclusion of materials ideas in Study Year Three reflected the lack of classroom opportunity to practice discernment with a wide variety of materials.

A partial answer to the question about the source of the children's ideas was provided by the Study Year Three survey question. Approximately 21% of these children responded that they used ideas from experiences outside the school classroom to modify Jane's Tower. Opportunities to watch new homes being built in the neighborhood and view real towers standing in fields were mentioned as sources of ideas about stability. Experiences inside their homes were also important and children wrote about hearing parents (mostly their fathers) talk about stability, viewing programs about structures on television, noticing that they tended to tip over when tying shoes, viewing tipped over chairs and tables and playing with "stuff" that tips over. Personal knowledge of stability constructed from these encounters clearly influenced some responses and could help account for the range and resiliency of materials and design ideas.

Other children (about 22%) wrote that their ideas for solving Jane's Tower were derived from school experiences and they mentioned watching videos at school and participating in activities from the previous year that involved structural stability. About 24% of the children did not identify a specific past experience which helped solve the problem, but rather wrote they got their ideas "from their brains," or "from just looking at it." This particular response does not necessarily rule out the influence of school experiences but rather shows how difficult it can be to identify idea sources. Regardless, children's responses about idea sources show that classroom and personal experiences were seen as equally important sources of information about structural stability and this could help account for differences between Study Year One and Three ideas.

Table 2 shows children in all grade levels had a very good chance of achieving a solution that would enhance the stability of Jane's Tower. Each child, however, could have achieved a successful tower through using a combination of useful and not useful ideas. For example, one child who achieved a successful tower suggested six different ideas in his answer–four useful and two not useful. These kinds of answers showed that some children had overlooked distinctions between useful and not useful ideas but had fortunately struck upon some ideas that would lead to overall success. This suggested that some children met with overall success despite offering unselective solutions and that perhaps overall success might have been attained through happenstance. If this was the case, perhaps overall success rates reported in this study were not as impressive as anticipated because they could have been due to the indiscriminate use of ideas. Be that as it may, children did offer many good ideas and perhaps the issue of helping children to refine ideas and offer more elegant, quality solutions would be a laudable goal of classroom teaching.

Table 3 shows that children in all grades were capable of achieving an elegant solution that used one useful idea to make Jane's Tower more stable. In Study Year Three, there was an increase in the percentage of children who achieved elegant solutions. A second analysis of children's solutions centered on whether inelegance in Study Year One was a good predictor of inelegance in Study Year Three. Data showed Grades One and Two children who offered inelegant solutions in Study Year One were very likely to offer inelegant solutions in Study Year Three. This suggested that these young children still needed practice in recognizing effective, efficient solutions. What seemed most confusing to them was the cardboard platform. Many of these children continued to propose changing the platform material from cardboard to an alternative material while neglecting to strengthen the supports. In contrast to this were those enrolled in Grade Three in Study Year One. The children in this group who offered inelegant solutions tended to abandon their indiscriminate thinking and offer much better solutions in Study Year Three. Thus, the presence of an inelegant solution in Grade One, Study Year Three was not a good predictor of inelegance in Study Year Three.

These observations hint at the complicated nature of the thinking that contributes to achieving elegant solutions. In order to propose an elegant solution to the Jane's Tower survey question, children needed a conceptual understanding of stability (possibly informed by personal experiences), the ability to sort and order this information, and the ability to apply such knowledge to Jane's Tower and make appropriate decisions (NAAIDT, 1994). In this study, it proved challenging for some young children to negotiate this complicated terrain.

Engineers who are also faced with constructing elegant solutions to technical problems speak of working through a similar process to achieve solutions. In engineering, "solutions to problems are not found or discovered, but selectively constructed to achieve a satisfactory outcome that satisfies the often contesting criteria of the situation" (Rowell, Gustafson, & Guilbert, 1997, p. 90). Elegant solutions, therefore, tend to be the product of sustained, informed, intellectual effort that may be difficult for some young children. Assisting children to practice discernment through sharing and analyzing ideas while keeping in mind the criteria that are to be met would be a useful goal of design technology teaching.

Conclusion

This study showed that children have a variety of ideas and an understanding of the concepts of structural stability even before engagement in a formal instructional program designed to teach this material. Some of the ideas that they proposed appear to be derived from a variety of past experiences; some are useful in solving the problem and others are not. After formal classroom activities about structural stability, some children showed an increased ability to discern between useful and not useful ideas, but they did not necessarily identify classroom experiences to this gain in discernment. In order to support children's conceptual understanding of structural stability, programs should encourage teachers to explore children's personal knowledge and design activities which assist children to consider and evaluate useful and not useful ideas.

Discussion about achieving elegant solutions showed that young children require assistance to properly solve technological problems. Technological problem solving is characterized by an interplay of ideas and children need time and support to sort through ideas, make decisions about which ideas are most likely to work, and then further refine these ideas into simple, successful solutions. In order to undertake this sustained, intellectual effort, children need to construct an appreciation for the value of elegant, quality solutions. Quality solutions are supported by teachers who provide opportunities for children "to be taught to apply technological knowledge, discuss and analyze their work, justify ideas, materials, and techniques they have used and to propose modifications and improvements" (NAAIDT, 1994, p. 53). Through this sustained effort, children participate in the iterative thinking or choice making which is inevitably part of technological problem solving. Through this they can learn to recognize that simple solutions are often as effective as complex ones. Productive areas for future research include exploring children's understanding of additional design technology concepts, exploring the role that children's personal knowledge plays in arriving at successful solutions, and studying the efficacy of school design technology programs.

An earlier version of this paper was presented at the Annual Meeting of the National Association for Research in Science Teaching (NARST), April 19-22, 1998, San Diego, CA. The support of this work by SSHRC-Northern Telecom Grant #812950007 is gratefully acknowledged.

References

Aikenhead, G. S. (1988). An analysis of four ways of assessing student beliefs about STS topics. *Journal of Research in Science Teaching*, *25*(8), 607-629.

Alberta Education (1996). *Alberta elementary science program.* Alberta: Alberta Education.

Anning, A. (1994). Dilemmas and opportunities of a new curriculum: Design and technology with young children. *International Journal of Technology and Design*, *4*, 155-177.

Anning, A. (1997). Teaching and learning how to design in schools. *Journal of Design and Technology Education, 2*(1), 50-52.

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.

Custer, R. L. (1995). Examining the dimensions of technology. *International Journal of Technology and Design Education*, *5*(5), 219-244.

Coenen-Van Den Bergh, R. (Ed.). (1987). *Report PATT conference: Volume 2 Contributions*. Netherlands: Bariet, Ruinen.

Davidson, M., Murphy, P., Hennessy, S., & McCormick, R. (1996). Technology is fun: Views of technology expressed by students aged 11-14 years. A paper presented at the *PATT-Sweden Conference*, Linkoping.

Davies, D. (1996). Professional design and primary children. *International Journal of Technology and Design Education*, *6*(1), 45-59.

Department of Education and Science (1985). *The curriculum from 5 to 16*. London: HMSO.

DES (1992). *Technology: Key stages 1, 2, and 3: A report by the HMI Inspectorate on the second year, 1991-92*. London: HMSO.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.). (1985). *Children's ideas in science*. Milton Keynes, U.K.; Open University.

Gadd, T., & Morton, D. (1992a). *Blueprints: Technology key stage 1*. Cheltenham: Stanley Thornes.

Gadd, T., & Morton, D. (1992b). *Blueprints: Technology key stage 2*. Cheltenham: Stanley Thornes.

Gardner, P. L., Penna, C., & Brass, K. (1990). Technology and science: meanings and educational implications. *Australian Science Teachers Journal*, *36*(3), 22-28.

Griffiths, A. K. (1994). A critical analysis and synthesis of research on students' chemistry misconceptions. Proceedings of the *1994 International Symposium on Problem Solving and Misconceptions in Chemistry and Physics*, the International Council of Association for Science Education.

Gustafson, B. J., & Rowell, P. M. (1997). Elementary children's awareness of strategies for modifying structures. In: Proceedings of the 8th *International Organization for Science and Technology Education (IOSTE) Symposium*, Calhoun, K., Panwar, R., & Shrum, S. (Eds.), August 17-22, 1996, Edmonton, Alberta.

Gustafson, B. J., & Rowell, P.M. (1998). Young children's awareness of structural strength and stability. *Alberta Science Education Journal*, *30*(2), 23-27.

Harrison, P., & Ryan, C. (1990). *Folens technology in action*. Dunstable: Kenley.

Johnsey, R. (1995). The design process—does it exist? *International Journal of Technology and Design Education*, *5*(3), 199-217.

Johnsey, R. (1997). Improving children's performance in the procedures of design and technology. *Journal of Design and Technology Education*, *2*(3), 201-207.

Kimbell, R., Stables, K., & Green, R. (1996). *Understanding practice in design and technology*. Buckingham: Open University.

Layton, D. (1993). *Technology's challenge to science education.* Philadelphia: Open University.

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.

McCormick, R. (1996). Conceptual and procedural knowledge. A paper presented at the Second *Jerusalem International Science and Technology Conference on Technology Education for a Changing Future: Theory, Policy and Practice*, Jerusalem, January 8-11, 1996.

McCormick, R., Hennessy, S., & Murphy, P. (1993). A pilot study of children's problem-solving processes. In Proceedings of the *International Conference on Design and Technology Educational Research and Curriculum Development*, J.S. Smith (Ed).

McCormick, R., Murphy, P., & Hennessy, S. (1994). Problem solving processes in technology education: A pilot study. *International Journal of Technology and Design Education, 4,* 5-34.

McCormick, R., Murphy, P., Hennessy, S., & Davidson, M. (1996, April). Problem solving in science and technology education. Paper presented at the *American Educational Research Association Annual Meeting*, New York, NY.

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

National Research Council (1996). *National science education standards*. Washington, DC: National Academy.

Northing, C. (1989). Teaching thinking skills: the development of design concepts in school pupils. *Journal of Art and Design, 8*(1), 23-35.

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

Pacey, A. (1983). *The culture of technology*. Cambridge, MA: MIT.

Rennie, L. J. (1987). Teachers' and pupils' perceptions of technology and the implications for curriculum. *Research in Science and Technological Education, 5*(2), 121-133.

Rennie, L. J., Treagust, D. F., & Kinnear, A. (1992). An evaluation of curriculum materials for teaching technology as a design process. *Research in Science and Technological Education, 10*(2), 203-217.

Roden, C. (1997). Young children's problem solving in design and technology: towards a taxonomy of strategies. *Journal of Design and Technology Education, 2*(1), 14-19.

Rowell, Patricia M., & Gustafson, Brenda J. (Eds.). (1998). *Problem solving through technology: Case studies in Alberta elementary classrooms*. University of Alberta: Centre for Mathematics, Science, and Technology Education.

Rowell, P. M., Gustafson, B. J., & Guilbert, S.M. (1997). Problem solving through technology: An interpretive dilemma. *Alberta Journal of Educational Research, XLIII* (2/3), 86-98.

Salvadori, M. (1990). *The art of construction*. Chicago: Chicago Review.
Symington, D. J. (1987). Technology in the primary school curriculum: teacher ideas. *Research in Science and Technological Education*, *5*(2), 167-172.
Tickle, L. (1990). *Design and technology in primary school classrooms.* London: Falmer.
Williams, P., & Jinks, D. (1985). *Design and technology 5-12*. London: Falmer.