

Heuristics: The Technology of Good Ideas

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Abstract

The change from technology education as the learning of a body of pre-defined knowledge and skills, to one where students are involved in problem-solving and innovation implies the need for changes in pedagogy. In March 1999 the Council on Technology Teacher Education funded a research project which examined ways in which it might be possible to improve technology education students' ability to come up with new ideas and to be innovative. This is seen as one important aspect of a new pedagogy for technology education. The project involved the development of a range of heuristics and the refinement of those heuristics after feedback from focus groups of technology teachers. Finally, the heuristics were trialed with technology education students in schools in three Australian states. The trial included both city and country schools. This paper reports on that study.

INTRODUCTION

Shulman (1987) has argued that all good teachers need three kinds of knowledge: content knowledge; pedagogical knowledge and pedagogical content knowledge. Content knowledge is defined by Shulman, as knowledge of the domain, or what is generally described as subject content. Pedagogical knowledge is described as the general abilities all teachers possess. These include the ability to motivate a class, the ability to plan lessons and the ability to establish and maintain an appropriate level of discipline within any class. Pedagogical content knowledge is described by Shulman as the knowledge of teaching skills and strategies that are specific to a domain or to particular topics within a domain. For example, knowledge of the best way to teach differential equations or computer numerical control (CNC) programming.

Banks (1999) has argued that Shulman's (1987) arguments are based on an essentially teacher-centered pedagogy that is inappropriate in a discipline where there are generally no correct answers to the problems students attempt to solve. While not taking issue with Banks, this study has worked on a somewhat broader assumption of what constitutes teaching strategies, or pedagogical content knowledge. That is, while technology has features that are quite different from other subjects, technology education still involves an interaction between teacher and student. That being the case, there may be better or worse ways in which the teacher manages their side of those interactions. Thus, the heuristics described later can be seen, in their broadest sense, as ideas that inform the teachers' interactions with students.

The rationale for the research project was that, as a consequence of the move from industrial arts to technology education, technology teachers do not yet have sufficient appropriate pedagogical content knowledge to develop innovative thinking in students and that there is a need to develop further, pedagogical content knowledge. The basis for this assertion does not come from detailed research as there appear to be few relevant studies conducted within

technology education. However, anecdotal evidence from technology teachers who report difficulty in providing students with strategies for generating new ideas, and the fact that the issue has been identified as an important research issue by the Council on Technology Teacher Education (CTTE), suggest that the assertion has face validity. On that basis it is argued that the identification, development and trialing of problem-solving heuristics is one contribution to the development of an appropriate pedagogical content knowledge for technology education.

BACKGROUND TO THE PROJECT

It is almost axiomatic to suggest that technology education is in a state of change. Significant change has been occurring since at least the mid nineteen eighties. The change has been in part a response to rapid technological change within industrial and post-industrial societies. The change in technology education has largely manifested itself in terms of changes in subject content, with such things as the introduction of computer-aided drafting and design, digital electronics, internet, and bio-technologies and robotics. In more recent times the emphasis on content change has shifted to include changes in the way teaching and learning occurs. One feature of this change has been a growing emphasis on the development of students' technological problem-solving abilities.

However, problem-solving has always been a feature of technology education. Indeed, others (Perkins, 1990; Anderson, 1993) have argued that most tasks that humans perform can be conceptualized as being problematic because all tasks contain a challenge. For example, the task of planing a piece of timber flat is problematic because the challenge is to perform the task with accuracy. Technology education has also involved more complex problem-solving in areas like automotive and electronic troubleshooting, where it is often the case that malfunctions will need to be diagnosed without the symptoms being able to be viewed directly, and where some interpretation is required.

In more recent initiatives in technology education (ITEA, 1996), however, there has been an explicit emphasis on certain kinds of problem-solving. The emphasis has been directed towards teaching and learning activities that develop creative problem-solving abilities. The Technology for All Americans project, which emphasizes the concept of "Technology Education as Innovation in Action" is the most recent and significant manifestation of this emphasis. Two examples of technological problems that explicitly involve creative problem-solving are invention and design. Designing and inventing are problem-solving activities that involve the higher order cognitive processes of analysis, synthesis and evaluation (Bloom, 1956).

Two strategies by which problems are solved are through the use of algorithms or heuristics. Algorithms are strategies that guarantee a solution to a problem, with a mathematical formula being a good example of an algorithm. An heuristic is defined as a strategy that increases the chance that a problem will be solved, but does not guarantee success. The design process, with all its variations, can be seen as an heuristic. Algorithms are useful for solving well-defined problems but are not able to be used to solve technological problems that require creativity. For example, there is no formula that can be applied to invent devices.

People solve problems in new domains by applying heuristics to declarative knowledge they have about the domain within which the problem resides. Declarative knowledge (Anderson, 1993) is defined as knowledge about something, for example, to know that a ball is round. Declarative knowledge is described as "knowledge that". New domains are taken to be

domains where the problem-solver may have knowledge about the domain in a declarative form but no specific procedural knowledge of how the problem is to be solved. Procedural knowledge (Anderson, 1993) is defined as knowledge of how to do something. For example, to know how to play basketball with the ball. Procedural knowledge is described as "knowledge how".

Experts in a domain have a large store of procedural knowledge that they can apply to any task within that domain. Novices in a domain, on the other hand, have some declarative knowledge, but a much smaller store of procedural knowledge. A consequence of this is that experts and novices solve problems differently. Experts in a domain simply apply their declarative and procedural knowledge to the problem and achieve a result. They draw on their understanding and apply a forward reasoning heuristic in solving the problem. A novice uses trial and error, and in the process, converts declarative knowledge to procedural knowledge. For example, a person who has never used a hammer may know that hammering is done by holding the hammer by the handle and striking the object with the head. By attempting and succeeding in hammering, the person will have converted 'knowledge that' to 'knowledge how'.

However, when solving problems requiring innovation such as in design and invention, problem-solvers are required to generate new ideas. In addition, school students are by definition, novice problem-solvers. Hence, technology students will need to make use of heuristic strategies that will assist them to generate new ideas to solve technology problems.

Heuristics have been the subject of research but have generally been dismissed as weak problem-solving strategies (Anderson, 1987). A closer look at the kinds of problems that have been the subject of research, and from which these judgement have been made reveals, however, that most problems that have been the subject of research into problem-solving strategies, have been simple and well defined, often to make them more amenable to particular research methodologies. Simple puzzles and mathematical problems are more easily solved by algorithms, in the form of formulas, than by heuristics.

Technological problems, on the other hand, are often complex and ill-defined and are generally not amenable to resolution by algorithms. There is evidence from research in information processing (Anderson, 1987), physics problem-solving (Clement, 1991), problem representation (Antonietti, 1991), invention (Weber, Moder & Solie, 1990) and creative thinking (Dominowski, 1995; Middleton, 1998) that for ill-defined and complex problems, heuristics provide very useful problem-solving strategies. Furthermore, for some complex problems, heuristics may be the only strategies that provide solutions (Kaufmann, 1990). This being the case, technology teachers need to have a store of problem-solving heuristics richly related to their conceptual understanding, and an understanding of when and how they are applicable, as part of their pedagogical content knowledge.

STATEMENT OF THE PROBLEM

What heuristics can technology teachers use to improve the creative, problem-solving abilities of Technology Education students?

RESEARCH DESIGN

The research design includes three major stages. The first stage was the development of those heuristics selected from the research literature and deemed to have promise for assisting students to solve technological problems. The second stage consisted of the research team

trialing particular heuristics and eliciting feedback from focus groups of technology teachers. The final stage involved trialing the heuristics with technology classes and evaluating the results of the trial.

RESULTS

The results of the project are presented in three sections. Firstly, the final ten heuristics developed for the project, and refined on the basis of teachers' feedback, are described below. Secondly, the results of the trialing of those heuristics which individual teachers were able to use with their classes are presented as a set of case studies. Lastly, a discussion of the results and directions for further research suggested by the study, are provided.

Heuristics

The ten heuristics described below have been developed, trialed with technology teachers and refined on the basis of the feedback from those teachers. Teachers in the trial schools have used one or more of the heuristics with their technology classes. It is important to note that while the researchers have suggested ways in which the heuristics may be employed, there was an expectation that teachers would vary these. In addition, some heuristics were included despite the researchers being unable to provide concrete ways in which they might be used. This was done in the belief that teachers may be able to devise ways to utilise those heuristics. The ten heuristics and related information presented to participating teachers are as follows:

1. Major adjustment approach

(Can we make this product, cheaper, simpler, do more things, do them quicker, better etc?). This heuristic comes from research on inventing by Weber, Moder and Solie (1990). For example, they cite the modification of a surface operating herbicide spray, to operate as a sub-soil spreader to reduce the quantity of spray and allow spraying in wind.

An example of use in a school may be "You have been presented with a set of plans for a children's wheeled toy. Your task is to change the toy so it can do different things". It may be useful to change the name used to describe the heuristic. The following were suggested: re-design, unpacking, modification, improving,

2. Joining approach

(can we join this product with part or all of another to create a new product?). An example that students may recognize is the transformer toys that, in one configuration, comprise a robot. By folding various parts the robot can be transformed into a plane.

An example of a possible way of using the heuristic with students may be to provide them with a brief that requires them to either combine two different kinds of objects from a particular type to produce a new object. For example, to combine two kinds of toys to produce a new toy or to combine two objects from different types of objects (for example, combine a toy with a seating device. The joining approach also comes from Weber et al (1990).

3. New material

(What can we make with this new material?)

To provide students with genuinely new material is probably difficult. However, many materials are new to most students. For example, acrylic is a relatively new material for most school students, and they can gain ideas by working with it and learning its properties. (what

can we do with acrylic?). Other materials that may have applications include Polycarbonate (Lexan) or Acrylonitrilebutadienestyrene (ABS). These materials will probably need to be used in conjunction with design briefs that will tend to lend themselves to solutions with the nominated materials. Some teachers in the trials suggested this heuristic could be used with an industry links project. The new material also comes from Weber et al (1990).

4. *New function*

(How can we change this product so it does something else?).

One workshop participant was at a school that had numerous spare science laboratory stools. In this school, the teacher decided to incorporate the heuristic by developing a brief based around re-engineering the stools for new functions. This heuristic may be particularly useful for design briefs based around use of recycled materials/objects. The new function heuristic is synthesized from research work by Finke and Slayton (1988).

5. *Functional analysis*

(What functions are provided by this device?)

If students are to gain most from engaging in designing they need to develop the ability to critically analyze the existing or possible future functions of objects they might design and of the functions of existing objects. The Functional Analysis heuristic was developed from research by Getzels and Csikszentmihalyi (1976) that suggested analysis of problems prior to attempting to solve them was important to success, particularly when new solutions were required.

This may only represent a slight variation on a strategy that teachers are already using, however, an emphasis on the functional requirements that will need to be incorporated into a new design may be useful in stimulating new ideas (possibly without students being aware that they are generating new ideas).

6. *Visualization*

(Visualize the problem before attempting to solve it). Antonietti (1991) has demonstrated that when solving complex problems, visualization of the problem, prior to attempting to solve the problem, is a heuristic that helps the problem-solver avoid the psychological blocks to creative thinking known as mechanization bias and functional fixedness. Mechanization bias is the tendency to solve a problem using routine techniques, when successful resolution of the problem requires the problem-solver to develop new ways to solve the problem. Functional fixedness is the tendency to see features of the problem as having only their usual function, when to solve the problem, the problem-solver needs to think of the features as having new functions. Finke and Slayton (1988) conducted experiments that suggest that visualization can be used to generate new ideas by requesting subjects to mentally manipulate images of objects until new and useful shapes emerge.

In a school setting, it may be possible to take a metacognitive approach and explain a little of how the mind works and how we process information and why this heuristic should help them come up with new ideas.

7. *Structural analogy*

(What objects have structural features similar to those required by the problem brief?)

In traditional workshop classes, it has often been regarded as good practice to display well made examples of objects to show students what is required. In using a design approach, this practice can have a detrimental effect in that it can induce pre-conceptualization. That is, if a

particular example of a solution is presented, it can be difficult for people to think up new solutions. However, if students are given examples of different classes of objects that have similar structural features, they can be assisted to come up with new ideas. (For example, a chair has similarities to a bridge pylon in that both have to withstand various static and dynamic loads)

8. Conceptual exploration

(Activities that explore structural or functional properties of solutions that have characteristics similar to real-world problems).

This is similar to some of the other heuristics. However, it may be more suitable for particular briefs than those related heuristics. For example, for briefs which require students to explore a range of required properties such as structural, aesthetic, functional, economic etc.

9. Resolving contradictions

(How can we design a strong yet lightweight chair?)

Some designers argue that one of the important aspects of producing a good design is to locate the inherent contradictions and resolve them. For example, strength versus weight, quality versus cost, complexity versus reliability. The heuristic may be introduced by having students identify the contradictions that are inherent in many designed objects. By introducing the concept of contradictions as something that students must address in the design of, for example, a seating device, it is possible to highlight the need to find suitable ways to joint the materials to provide sufficient strength, while not unduly compromising weight or cost.

10. Attribute analysis

(What are the positive and negative features of product X?)

Unless products impact on them directly in a positive or negative way, students tend to remain unaware of the particular attributes of many everyday products. However, they are adept at analyzing products if given the task. This analysis can be used to develop the student's "ideal solution" (exploring limitations and possibilities of existing products).

Case Studies

The format for reporting the case studies was developed in conjunction with the teachers involved in the project. Teachers in the trial felt that before teachers would use the heuristics they would want to know the geographical, social, economic and cultural contexts of the setting for each case study report. Their view was that this information would be important in helping them make the decision about the use of any heuristic. The format for the case study reports includes a description of the context, project brief, heuristic/s used, including variations, and reflections on the trial by teachers. These reflections include student work, the teaching process and use of the heuristics. Some schools requested anonymity, so for consistency, no schools or teachers are identified.

Case study 1

Setting for the case study

Case study 1 was set in a high school in a town that serves as a regional centre for a largely rural area. Many of the students live on farms and commute to school. The school is one of two state schools in the town. The school has an enrolment of 950 students between years 8 and 12 (approximately 13-16 years of age). The class involved in the study was a year 8

technology class with twenty-four students with equal numbers of boys and girls. The project that developed from the brief lasted for five weeks.

Project brief

The project brief required students to design a device for storing and transporting school items such as pencils, pens, white-out, etc. The brief indicated that students needed to take into account their own circumstances in addressing the brief. For example, students who rode bicycles to school may have different constraints and possibilities from students who came by bus or car.

Heuristic/s used

Students were introduced to the brief and the teacher initiated a discussion of each of the heuristics and the students decided, as a class, to use the Major Adjustment approach. The students were keen to do a project that was their own design and approached the task and heuristic with great enthusiasm.

Reflection on student work

I was surprised at the student's own ideas, as they were very well thought out. They produced an amazing range of designs for the same brief. Most were good and the students were able to proceed and make them. Some proved difficult to manufacture. On reflecting on why the project worked, I think it worked because of the heuristic used, but also because I spent quite a bit of time explaining the heuristic, both to individual students and to groups of students. It also worked because the project avoided the problems of preconceptualization because they were taking an existing idea and modifying it.

Reflections on teaching

I enjoyed doing the design project and I feel the students felt the same. Some of the students could not match the design with their skills in manufacturing and I found that I had to help a lot in that area. I found it to be a rather stressful way of teaching and think that a teacher's aide is a must in the classroom design situation. I feel the introduction of technology education in the primary school will improve students' learning as they will come to the high school with the knowledge and general technological orientation to make the most of both their design skills and of the heuristics for idea generation. Having said that, I was impressed with the innovative designs the class produced.

Reflections on the heuristics

The heuristics certainly seemed to provide students with a concrete starting point. No students responded to the brief with "I can't think of any ideas". It also provided me with a concrete way to interact with students without taking over the project and getting the student started by giving them my ideas.

Case study 2

Setting for the case study

The school for this case study is a suburban state school in a capital city. The school has an enrolment of approximately 720 students, with 70% of students coming from suburbs outside the nominated feeder areas. The suburbs the student population comes from could be described as moderately affluent. The class was year 8 Technology with eleven girls and twelve boys.

Project brief

The project brief is a popular one that was taken from the world wide web, where students are required to design and build a model car to achieve the highest speed possible over a 20 meter track, using a carbon dioxide (CO₂) canister for motive power (often called the CO₂ dragster project).

Heuristic/s used

Students were introduced to the Functional Analysis heuristic. After an introduction I spoke to the students about the non-negotiable elements of the design, such as maximum size and quantity of materials, and provide a summary sheet for this.

Reflection on student work

After introduction of the constraints we had a discussion of what would make a car go fast and we discussed weight and size vs. wind resistance. From here we discussed the designs of dragsters in real life after which students sketched out their ideas on paper. Students then formed into small groups to discuss their ideas and to critically analyze both their ideas and the ideas raised in the general class discussion. Students then worked on individual designs, re-doing sketches to take account of the discussions.

When satisfied that they had developed satisfactory sketched designs, full-size working drawings of the top and side views were produced. These became templates for the manufacturing stage, and were produced in parallel with discussions concerning the best approach to making the project. That is, the need to produce an accurate measured drawing stimulated students into making qualitative decisions about dimensions, proportions and manufacturing techniques.

The students were keen to get onto the making side of this project and were less keen on the design. However when no models were presented to the students and they realized that they had to come up with their own design they were happy to use the heuristic. About 75% of the students really enjoyed this process of having tight restrictions to work to but also the opportunity to do what they want. Some students are not used to working in this environment. Some students have really excelled at this and have developed many new skills on a just-in-time principle. Others have stayed within the skill base that they know and are comfortable with.

Reflection on teaching

This is the second time I have used this project, but the first time I have used the heuristic, so I was able to compare experiences. The project worked well and I would think that for the next time there will need to be minimal changes. To extend the unit I would like students to take photos and develop PowerPoint presentations and load their work onto the Internet.

Reflection on the heuristics

Initially, the students were not particularly interested in hearing about the heuristic as they were keen to get to the stage of making something. However, once they started to grapple with the requirements of the brief, the heuristic did appear to provide most with a useful starting point. From my point of view as a teacher, it was a very good way to respond to students' requests for ideas. In that sense I think they got more out of the project because the problem remained theirs to solve.

Case Study 3

Setting for the case study

The setting for case study 3 is a public school with an enrolment of 1150. The school is located in a country town that is the regional centre for a large farming district. The township is situated approximately two and a half hours by car from the state capital. It caters for all students from year 8 to year 12. Occasionally a number of mature age students undertake studies at the school as well. A large number of students travel to school by bus from the surrounding areas.

The Industrial Technology and Design subjects are popular with the students at this school, with approximately 750 enrolled in the various subjects in the area. Some students undertake more than one subject. All year 8's undertake Industrial Technology. Year 9's and 10's chose any combination of Industrial Technology A, Industrial Technology B and Graphics. The senior school subjects are Industry Level Training in Construction, Industry Level Training in Engineering (Manufacturing), Technology Studies and Graphics. The group used for the project was year 10 Industrial Technology. The class has three females and twenty-one males.

Project brief

The starting point for this project was a coffee table. Students were required to design a table, but then modify the design so the table provided an additional function, for example, as a games table with storage facilities.

Heuristic/s used

Due to the planning and structure of our course subjects, we were only able to include elements of the heuristics during this year. The planning for next year and beyond includes more heuristics in a more formal situation. We are developing a new approach but had this year basically planned. A number of staff plan to include some heuristics in terms 2, 3 and 4. With my year 10 Industrial Technology class I introduced the New Function and Functional Analysis heuristic.

Reflection on student work

The idea of developing a design for an everyday item such as an occasional table and modifying it, appealed to most students. Many opted for modifying the tables to serve as games tables. This raised the issue of storage of game pieces. The major adjustment heuristic started the ideas flowing. The fact that it required different kinds of thinking appealed to them. They started to think of alternatives and different ideas.

Reflection on teaching

The design folio I used for the table design asked for students to find pictures of tables. This was included in the investigation phase. The next part was to brainstorm a list of uses for a table then refine the list to their own personal requirements. This step was important because it got the students thinking about what they were to do. They started to analyze the function of a table and how and why that impacted on their ideas. I actually managed to get some work out of some students who think the best option is to do nothing. They must have seen some value in this because they were actually working.

It opened possibilities that would not have been possible if we just made "the standard coffee table we have made for the last ??? years." I have students with completely different designs but still requiring similar construction methods which appeals to the more traditional teachers who still see the subject as essentially a skill-based one.

Reflection on heuristics

The major adjustment heuristic was the principal one used for the project, but I realized that, on reflection, I was using more of them as I discussed issues that arose with particular students. It seemed to me that for this project the process of using a principal heuristic to get the project started, followed by other heuristics, to overcome individual problems, worked particularly well.

Next term I propose to try the "New material" heuristic in a more formal sort of way. One unit we will be doing is on the Plastics Injection Molder, which is new to the students and me. It will be a steep learning curve for all of us. We will also be doing different things with recyclable material - designing new products from old materials.

Case Study 4

Setting for case study

The school for case study 4 is a suburban junior high school (Grades 7-10) in a capital city. The school has an enrolment of 620. The feeder areas for the school include suburbs with a high disposable income and suburbs with high levels of unemployment. The class had only been together since the start of that semester, approximately six weeks. The class involved in the research was a year 9 Industrial Design group. There were three females and twenty-two males in the class.

Project brief

The project brief was linked to an existing project the students had already completed. This consisted of an electronic device. Each student had designed a device to perform a particular function. All the devices required containers, to protect them and to allow them to function, for example, to provide displays, locate switches, batteries, etc. However, as the devices differed in their function and configuration, each required a purpose-built container. The brief for this project was to design and build a case that satisfied the particular requirements of each device.

Heuristic/s used

The students were presented with two heuristics. These were the Functional Analysis and Major Adjustment approach. Students were given the choice of using one or the other or both, and the students were required to undertake the research to establish which heuristic was most appropriate for their project. For example, if a project circuit could be accommodated in a modified form of an existing container design, then the student was likely to opt for this heuristic. If, on the other hand, the requirements of the device were such that no existing container design came close to being suitable, then the student was required to undertake an analysis of the exact requirements of the container for their device.

Reflection on student work

The students were motivated to complete the project. In part this was because they had already completed the "working" part in terms of the circuit, and were keen to finalize the project so they could use the device. Creating a container that not only met the functional demands of the device in terms of ergonomics, replacement of batteries, display screens etc, but also looked good in terms of how students thought the object should look was important to most students.

Reflection on teaching

The separation of the project into two parts seemed to make the project more manageable, in that each student was able to tackle smaller aspects of the problem. This two-stage process also tended to provide an incentive to develop a solution for the container problem. As I did not use any heuristics for the first stage I wonder if it would have been possible to generate more or better ideas for that stage.

Reflection on heuristics

For this project, the heuristics did not provide a motivator or starting point for the work (of designing a container for the electronic circuit). However, the functional analysis heuristic was important in helping students focus on, not only the aesthetics of the container, which they were keen to do, but also on the functional aspects.

Case Study 5

Setting for case study

The school for case study 5 is a suburban junior high school (Grades 7-10) in a capital city. The school has an enrolment of 620. The feeder areas for the school include suburbs with a high disposable income and suburbs with high levels of unemployment. The group was a year 10 Industrial Design class. They had been together for that subject for the previous semester, during which time they covered, among other topics, basic design processes.

Project brief

The design brief for the project was titled "What Goes Up, Must Come Down". The local show is approaching, and as a class we will be running a stall to sell gliders. The design brief is to design and construct a glider, which flies with only the assistance of the wind. You will need to research the topic. Suggested starting points for the research include principles of flight, cost, material and size. This was a topic the students had some tacit knowledge of, having all made paper airplanes at some stage prior to the project. However, to successfully design and make a saleable glider it was necessary for the students to augment their tacit knowledge with research.

Heuristic/s used

Given the relative complexity of the issues involved in flight I opted for the functional analysis heuristic. In addition, as the students were likely to be using materials in a new way I also introduced the heuristic of new material to them.

Students were required to research gliders, including glider types, aerodynamics, and the function of various components such as wings, tail planes and fins. Students considered materials and dimensions as well as construction techniques. A range of information was provided to the students, by the teacher, in the form of a handout. This gave directions for basic wing construction, gluing and other construction techniques.

Reflection on student work

The project itself absorbed the interest of most students. Each student came up with five different possible solutions to the brief and their preferred solution. Students, within the limits of materials available, experimented with shape and dimension/weight of materials as well as construction techniques available. Students appeared to value the restrictions of the brief and engaged well with the functional analysis aspect of the project.

Reflections on teaching

Using the functional analysis heuristic where students examined a range of existing gliders certainly appeared to initiate student thinking. The enthusiasm generated during this stage was important for the success of the project. Most students were able to extrapolate from the models examined to their own individual designs and incorporate ideas into their designs.

The successful testing of the gliders was also an important part of the process and students received a boost from this testing and in some cases redesign/modification. Some students asked if they could work outside the brief. This was allowed and a number of variations to the brief were undertaken, for example, some made oversize gliders. However, this strategy appeared to distract those students from the essential challenge of the project and the solutions they produced tended to fall short of both their own modified brief, and the requirements of the brief presented to the class. I would be reluctant to make this variation if I repeat this project in the future.

Reflections on the heuristic

The functional analysis heuristic was very important in helping students to focus on the requirements of a project that appears simple but which in fact has a range of complex aspects to it.

Case Study 6

Setting for the case study

The school for case study 6 is a state junior high school in an affluent suburb in a capital city. The school has an enrolment of 720 students in grades 7 to 10. The students involved in the research project were a year 10 Graphics class. The class had been together for about two weeks at the time the project was started. The students had some experience of technical drawing at the start of the project. There were twenty-five students in the class with five females and twenty males.

Project brief

The brief for the project was to take an existing shoe, choose a theme and modify and redesign the shoe. The length of time allocated to the task was 3 weeks.

Heuristic/s used

In terms of the heuristics, a number were used in the project. These comprised New Function, Functional Analysis, Visualization and Conceptual Exploration. The project and what was regarded as the key heuristic (new function) were introduced through demonstration and by example. For example, the teacher took a shoe (in front of class), chose a theme and then proceeded to redesign to produce an exemplar. Students then went and worked individually on their own project.

Reflection on student work

Students were enthusiastic about the project and finished with a good feeling about what they did. The teacher thought that this was a good project based on the enthusiasm from students and the range of solutions finally produced. The new function idea worked well with students, particularly in connection to an item of personal apparel.

Many students needed considerable help in working with what was, for them, a new material, as they were required to produce a full size model using an old shoe. Working the materials

was a problem for some students. Some students modified their initial ideas when faced with the reality of production and materials.

Reflection on teaching

I would repeat this approach again, perhaps with different personal apparel. The teacher demonstration did not trigger the range of ideas expected but rather appeared to narrow the thinking of students. The teacher thought it gave them the idea that they would make what the teacher wanted to gain the most marks, rather than experiment themselves.

Evaluations at various stages were very successful in allowing students to see the work of others and give constructive criticism of their own work. They were critical of themselves and how they were performing. Next time I would not give a demonstration (how the teacher would do it). Rather a range of options or some previous student work as a stimulus.

Reflection on the heuristic

The heuristics worked well for two reasons. Firstly, using the new function heuristic provided a way for students to get started on responding to the problem, so introducing it at the same time as the brief worked well. The other heuristics were introduced as and when needed and they were important in helping students get past mental blocks in their thinking. It is not possible to quantify, but my feeling is that the heuristics resulted in a wider range of solutions and a range of solutions that were particularly innovative.

Case Study 7

Setting for the case study

The school for case study 7 is a state junior high school in a mostly affluent suburb close to the centre of a capital city. The school has an enrolment of approximately 700 students in grades 7 to 10. The students involved in the research project were a year 8 Graphics class. The class had been together for only one week at the time the project was started. There were thirty students in the class with fourteen females and sixteen males.

Project brief

The brief was based on students responding to a scenario. A scenario depicting an over-populated planet was given and students were asked to organize the immigration of some 2000 people to neighboring planets. Students are asked to design transport, present a new settlement constitution, design a plan for a basic house for the new colony, and develop a new planet exploration transport system. The brief had optional extension activities. These included the production of an advertisement for interested immigrants, an environmental policy, power, food and waste disposal policies and a timeline for a 20 year building program. Environmental factors for the new planet were described as including a low oxygen atmosphere, a largely desert landscape, the presence of strong winds and 45% of the surface of the planet consisting of ocean. Students were required to take these factors into account in responding to the brief, develop plans for all aspects of the brief and to produce and present a model of their proposed housing.

Heuristic/s used

Several heuristics were used in the project. As can be seen from the project description it is complex in terms of the types of problems the students were required to address. It was stated that the overall object was to create opportunities for students to think laterally working both individually and in a group. In terms of the "Revised Heuristics" sheet the Heuristics used were new function, functional analysis, visualization, conceptual exploration,

resolving contradictions and attribute analysis. These were all used deliberately at various stages of the project.

Initially the heuristic was introduced as part of a story. World out of resources, overpopulated, leaders given opportunity to emigrate. Choose a planet, environment type, etc. Group discussion was used to stimulate ideas, a form of 'mind mapping'. Various aspects of the project were focused upon in this way over the project period.

Reflections on teaching

The story approach in setting the problems of the project worked very well. Students were drawn into a fantasy world, encouraging their imagination. They felt freer to try different ideas initially and then worked through the practicalities of the ideas in relation to the design brief. Students generally were enthusiastic and drawn into the project.

Mind mapping (as a whole group) worked well. It gave the students opportunities to feed off each other and was usually a fun process in developing a range of different solutions. Students enjoyed the process and usually returned to their smaller groups or individual ideas re-invigorated.

On the next occasion I use this project I will incorporate more initial practice with freehand drawing and practice in sketching concepts before letting students use computers to produce sketches and plans. A number of students argued that they could not do freehand sketching and would like to go straight on to produce CAD plans. This did not work and the ideas they produced were cramped and stilted at the outset.

Reflection on the heuristic

There was never a focus on a heuristic in the presentation in the sense that students were introduced to a heuristic. Focus was maintained on the project idea, which was taken up enthusiastically by all the students in the group. There were some obvious 'mental blocks' for some students but this was generally overcome through a combination of heuristics, group work and idea sharing and building (mind mapping). Some students were held up by their lack of technical skills such as being able to successfully represent ideas in sketch form or use computer graphics.

Case Study 8

Setting for the case study

The school for case study 8 is a suburban junior high school (Grades 7-10) in an inner suburb of a capital city. The school has an enrolment of approximately 600. The feeder areas for the school include suburbs with a high disposable income and suburbs with high levels of unemployment. The school attracts about 40% of its enrolment from outside its feeder area. The group was a year 8 Industrial Design class of twenty-four students with equal numbers of females and males. They had been together for that subject for about ten weeks. This was their first major design project.

Project brief.

Students were asked to choose two inventions from the twentieth century and combine them to come up with a new product. Students researched significant 20th Century inventions or technological developments and made choices from their research.

Heuristics used

The two heuristics incorporated in this project were Joining Approach and New Function. Introduction took the form of a historical overview of 20thC inventions using teacher-centered presentation with overheads. In the invention selection phase students were encouraged to talk about their selections and why the selection was made. The group explored possible combinations before individuals started their own projects. Thus, the heuristics for this project were built into the brief rather than being something that was applied to the problem after the brief.

Reflections on student work

Students' initial reactions were to pick what appeared to them as the easiest combinations. However, while the Joining heuristic made this a relatively easy task, establishing the new function proved more difficult, and many found their initial combinations were inappropriate. After a couple of lessons the teacher led a whole class review into the selections with a group 'think tank' approach to get things moving again. The students investigated limitations and the realities of the combinations (and in doing so used the heuristic Attribute Analysis).

Reflections on teaching

It was unclear how practical the brief expected the combinations to be or if this was treated more as a fantasy and imagination exercise). The project worked well from the point of view of developing student understanding of compatible functions. This was seen to be a good starting design experience for students, introducing them to thinking processes, research, and understandings about a range of materials and a global picture of technology.

Reflections on heuristics

For this project the heuristics used were important, particularly in the way students used the joining approach as a starting point and then used the new function heuristic when problems arose. The heuristics worked well despite them not being introduced as a starting process.

Table 1. Summary details of case study groups

School type	Grade	Class size	Gender F:M	Subject	Heuristic/s
Rural	8	24	12:12	Technology	Major adjustment
Suburban	8	23	11:12	Technology	Functional Analysis
Rural	10	24	3:21	Industrial technology	New function & functional analysis
Suburban	9	25	3: 22	Industrial Design	Joining approach
Suburban	10	24	2:22	Industrial Design	Functional analysis
Suburban	10	25	5:20	Graphics	New function, functional analysis, visualization & conceptual exploration
Suburban	8	30	14: 16	Graphics	New function, functional analysis, visualization, conceptual exploration, resolving contradictions & attribute analysis
Suburban	8	24	12:12	Industrial Design	Joining approach & new function.

DISCUSSION

During this study, ten heuristics were developed prior to trialing. Teachers who trialed the heuristics with their classes were given complete freedom in terms of which heuristic or combination of heuristics they used with their class. During the study eight of the ten heuristics were trialed.

For seven of the groups the heuristics were seen as being useful in providing a starting point for the generation of ideas. For six groups the heuristics were useful for teachers to suggest to students as ways of resolving mental blocks during the process of developing their designs.

One process to emerge in the study was the use of a two-stage process where students were initially presented with a brief and an heuristic for generating ideas. As the students proceeded to create their designs, they came up against problems. Teachers reported that other heuristics were then useful for resolving these blocks.

One unintended outcome of the research was concerned with more general aspects of teaching. That is, a number of teachers who were willing, and in some cases enthusiastic to be involved in the research, found that they were unable initially, to utilize any of the heuristics. The reason for this inability was that in trying to implement the heuristics, they realized that their teaching was more teacher-directed, and less based on student problem-solving than they realized, or were comfortable with. However, we see this outcome as a positive one for the research because in a number of schools, the attempt to introduce the heuristics provided the impetus for a departmental review of the aims of their courses and of the teaching strategies for achieving those aims. It did, however, delay the collection of case study reports in some cases and in some cases the reports are still to be delivered.

There were a number of unforeseen difficulties encountered during the project. The first and most general one was in convincing teachers to become involved. The resistance appeared to be based on conceptions like "I'm involved in practical education and that has nothing to do with research". Others were unconvinced that the results of research would be of any use to their teaching. Others appeared to be reluctant to be involved in something that might expose their teaching.

A second difficulty was inherent in an unavoidable aspect of the design of the research. It was necessary to recruit teachers who understood, were sympathetic to and to some extent at least, were engaged in what is often described as problem-based learning. The reason for this is that teachers will only engage successfully in activities they feel comfortable with. However, these same teacher, having an understanding of problem-based learning, were, by virtue of their experience, likely to gain less from the research experience than a teacher who had no experience with this kind of teaching/learning. However, to recruit teachers who were still using completely directed teaching strategies, was likely to result in no gain due to an inability to utilize the heuristics. The problem was generally resolved through discussion, however, it did result in a number of teachers who were involved in the focus groups not being involved in the trials.

FURTHER RESEARCH

The research has provided a starting point for the development of a new pedagogy for technology education, concerned with the development of inventive thinking. It has also demonstrated that concrete strategies to assist students to engage in technological problem-solving can provide the stimulus for more widespread examinations of the way teaching and learning occurs in technology education. However, the research is only a small, pilot study

and as qualitative research was engaged in theory-building rather than theory-proving. A larger study that attempts to unpack the psychology of technological problem-solving in a way that allows for broader generalizations to be made should prove useful.

The contexts within which the heuristics were applied were only described after the event. That is, teachers provided a brief profile of the community and school context of the class used for the trial. Research into the social and cultural contexts within which learning takes place suggest that these have an important influence on learning. The way in which these factors may influence the type and quality of problem-solving students engage in a technology education class should be the subject of further research.

Lastly, the heuristics trialed in the research were an element the teacher introduced into the learning environment. However, it does raise the question of learning environments in general. That is, what is the most appropriate environment to promote learning that is in accord with the idea of technology education as innovation in action?

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