AC 2012-5385: OBSERVATIONAL STUDY OF STUDENTS' INDIVIDUAL HEURISTICS WHEN SOLVING TECHNOLOGICAL PROBLEMS

Mr. Jonathan Gerard Spillane, University of Limerick
Dr. Niall Seery, University of Limerick
Mr. Donal Canty, University of Limerick
Dr. Diarmaid Lane, University of Limerick

Observational study of students' individual heuristics when solving technological problems

Abstract:
The overall aim of education is the development of creative, critical thinking and problem-solving future citizens who will be able to positively contribute (individually and collectively) to society. Yet, research has highlighted the misalignment between theory (curriculum) and practice (teaching practices, learning experiences) in the attainment of this aim. The objective of technology education is to produce technologically capable and literate people. Problem-solving and value judgements have been highlighted as critical areas in the development of technological capability [1] and technological literacy [2].

This paper investigates students' (12 to 15-year-olds) individual heuristics when problem solving during a prescribed ICT based computer task. The program attempts to elicit critical thinking and reasoning skills (deductive/abductive/inductive). The development and application of these skills became apparent as students progressed through the task. Web-capture software was used to track each student's progress and monitor their decision making.

A multidimensional problem-solving framework was employed when observing participants attempts. The problem-solving framework looked at four key stages: *Identifying, Planning, Implementing*, and *Evaluating*. This was supported by the sub-cycle of *conjecture*, *test*, and *evaluate (accept/reject)* method presented by Carlson and Bloom [3] used to analyse mathematical problem-solving. Simultaneously audio responses were also captured, which gave researchers a valuable and rich data set to interpret individual heuristics, conceptual knowledge and decision making.

The findings presented in this paper illustrate a clear connection between Attitudes, Skills and Knowledge (ASK) and the development of strategic knowledge and successful problem solving. The use of both conscious and subconscious recognition of signage, symbolism and pattern recognition in the problem-solving process provided the researcher with insight into the type of individual heuristics employed and the performance efficacy of student attempts.

Introduction:

Technology education is formally introduced to pupils at early second level (Junior Certificate) through four voluntary subjects: Materials Technology (Wood), Technical Graphics, Metalwork and Technology. These subjects have voluntary parent subjects at senior level (Leaving Certificate). The objective of technology education in the Republic of Ireland at Junior Cycle is to produce a technologically-capable future citizen who will be able to contribute positively to society [4]. The issue with this objective is that there is currently no distinguished level to state that either a person is technologically capable or technologically literate or not. The implementation of teaching technology in the different subject areas brings in altering opinions on theory and practice methods [5]. For a pupil to be considered technologically capable a set of key components where derived by the NCCA [4] shown below in five specific areas:

- Design & Communication
- Materials & Processing
- Health & Safety
- Energy & Control
- Technology, Society and the Environment.

This paper looks at a pilot study of the initial task area in a battery tasks (five in total, based on the key aspects). Each task had been specifically designed to elicit indicators of technological capabilities of pupils at Junior Cycle. This paper will focus on the initial Design & Communication task. Also outlined in the paper is the importance of problem-solving and individual heuristics in technology education.

Technological Capability:

Technological Capability has been defined as 'the ability to make effective use of technological knowledge' [6]. The development and learning in movement from tacit to explicit knowledge that is gained through the practical activity was described by Kimbell as '*thought in action'* and is seen '*as the cornerstone capability of design and technology*'[7]; capability is seen as 'the power to produce an effect' [8]. '*Capability is more than a collection of separate abilities*' – (Farrell & Patterson 1993) cited in [9]. Only when there is an acceptance or acknowledgment of both knowledge and skills can the term capability be used in a specific knowledge-task context. If the pupil develops technological knowledge, technological skills or values/attitudes towards technology singularly then they will only gain an '*ability'* in that area. If the concepts are developed with an inter-relationship being established then '*capability*' is achieved [10]

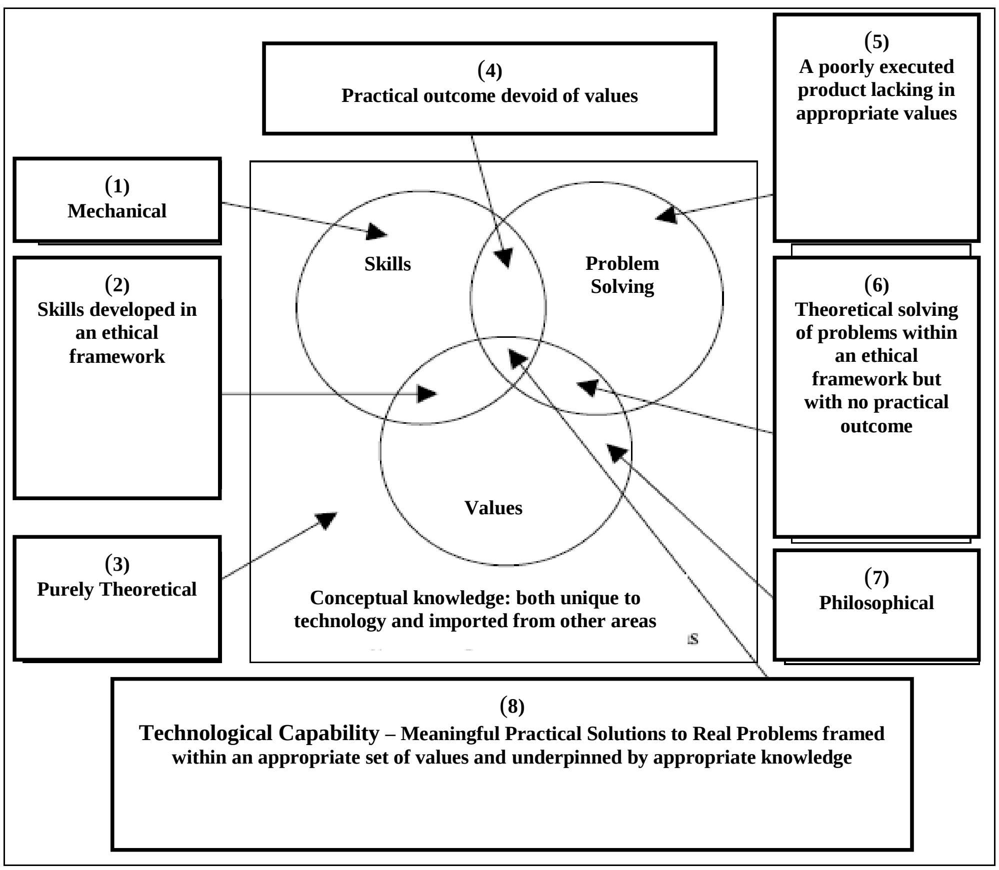

Figure-1: Gibson's Technological Capability[1]

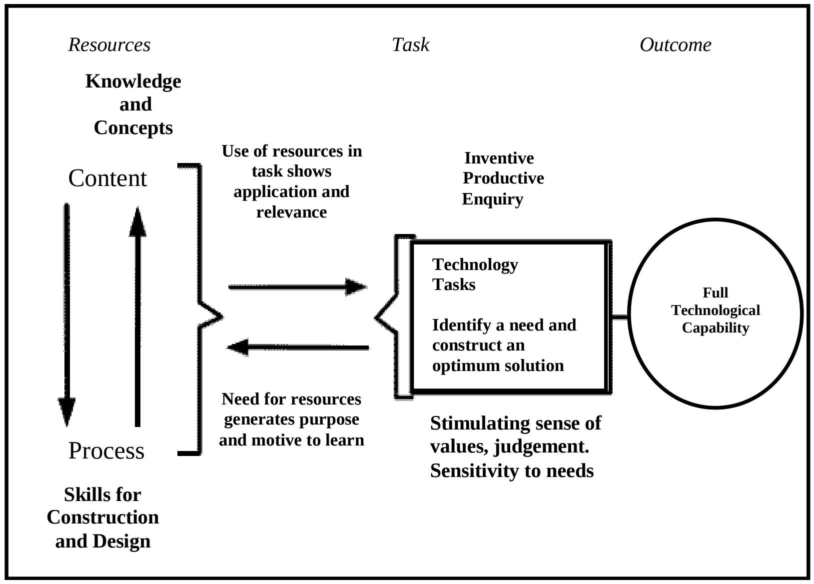

Figure 2: Black and Harrison's model of technology education

The concept of a Task-Action-Capability (TAC) framework (fig. 2) was developed by Black and Harrison [11]. This shows the relationship between content and process; the knowledge and concept of the task (content) vertical arrows show the interaction with the skills for construction and design (Process). The task is dependent on the content and process, the interaction of which can be seen in the horizontal lines. Outside the task box are the personal (inventive, productive and enquiry) and intrapersonal skills (judging and valuing) that the pupil develops through the production of the task. This allows for the development of technological capability through "experience of tackling tasks" which Black and Harrison deem essential.

Problem-solving:

The area of problem-solving and students' individual heuristics has been highlighted as an area of concern by researchers with a view to developing school practice [12]. For the purpose of this paper problem-solving will be based on Schoenfeld's definition of a problem, that the individual attempting a problem doesn't know how to solve it with familiarity or by comfortable routine.

Sternberg [13] promoted the problem-solving cycle which included (a) Problem Identification, (b) Definition of a problem, (c) Constructing a strategy for problem-solving, (d) Organising information about the problem, (e) Allocation of resources, (f) Monitoring problem-solving and (g) Evaluating the problem. Sternberg also stressed the need to be flexible in undertaking problem-solving task. As inventive as we can be in solving problems, two cognitive tendencies - 'Confirmation bias' and 'Fixation' - often interfere [14]. Confirmation bias is where the problem-solve shows reluctance to seek information that might disprove his/her beliefs. A major problem with fixation is inability to see the problem from a fresh perspective.

Problem-solving has been recognised by researchers as having four distinct phases [3, 15]. The problem-solving framework looked at four key stages: *Identifying, Planning, Implementing* and *Evaluating*, this was supported by the sub-cycle of *conjecture, test*, and *evaluate (accept/reject)* method presented by Carlson and Bloom [3] used to analyse mathematical problem- solving. The use and efficacy of individual heuristics in the development of understanding during the problem-solving task was of key interest to the author.

Heuristics: What are they? Why are they important?

The word heuristic means "to find out, discover" and stems from the ancient Greek word "*heuriskei"*. They have been described as building blocks of the mind to aid in the development of reasoning and understanding. Gigerenzer defined heuristics as:

"*A heuristic is a strategy that ignores part of the information, with the goal of making decision more quickly, frugally, and/or accurately than more complex methods*" [16]

It has to be noted that the use of heuristics in problem-solving does not guarantee a correct or positive outcome. Polya was quite definite in his view that heuristics are not infallible and that they are to be contrasted with deductive reasoning. There are an infinite number of heuristics, an adaptive toolbox was proposed by Todd & Gigenzer [17] in which an array of different types of fast and frugal heuristics were proposed for solving different types of problems. The number of options that are available in a decision situation and how many are chosen will partly determine the heuristics employed.

Shan & Oppenheimer [18] proposed that all heuristics rely on effort reduction by one or more of the following:
(1) Examining fewer cues
(2) Reducing the effort of retrieving cue values
(3) Simplifying the weighting of cues
(4*)* Integrating less information
(5) Examining fewer alternatives

The importance of developing search rules, stopping rules, and decision rules was highlighted by Raab & Gignezer [19]. This led to the question, does the nature of the task impact on the effectiveness of the participant? Or is it simply the level at which they (the problem-solver) have developed their search rule, stopping rule, and/or decision rule.

The capacity to highlight trends in problem-solving and individual heuristics that could be monitored and tracked across a broad range (five themed areas) was considered. The divergent nature of technology meant that the method employed in codifying and assessing would have to be developed in a proactive/ reactive manner.

Method

Test tool
The Information Communication Technology (ICT) "Portals" which was developed by Value was selected as the main test tool for the initial domain dominant task (Design & Communication). The computer simulation was developed to elicit participants' problem-solving skills and has since been used to promote learning in the STEM subject areas under the 'Learning through Portals' project. The use of critical thinking and reasoning skills (deductive/abductive/inductive) is required if the participant is to progress far in the activity. The availability of information (signage, audio, imagery) for participants to consciously or sub-consciously recognise/disregard throughout the programme was one of the key factors in its selection as main test tool. This added a real life experience in the test scenario to observe participants problem-solving skills and reasoning abilities.
Focus of using this tool was for the Design & Communication theme, each of the themed areas are domain dominant as technology is multifaceted that anyone activity will have the potential to observe knowledge, skills and attitudes under different areas. The computer simulation allows for

numerous different individual heuristics to be employed by the participant which should provide a rich source of data to inform on specific incidents technological capability, problem-solving, and reasoning abilities.

Format

Participants were given game controls schemata and were allocated one minute to familiarize themselves with the computer simulation in a controlled environment (test chamber) before attempting to complete level 1. The design of task was to elicit participants problem identifying abilities as it was the first time that they would have see or played computer simulation. The constraints were minimised (no time constraint). This was specifically planned to view participants reasoning capacity and the approach they take on defining the problem area when constraints are minimised.
Participants were asked to sketch the layout of the entire level with as much information as they felt relevant with the intention of supplying another person with enough information to complete this level. The change in nature of testing was designed specifically to observe the type/use and efficiency of individual heuristic(s) employed in a successful attempt in communicating relevant information (as determined by participant) to complete level 1. The task was designed to elicit participant's spacial abilities, reasoning abilities, and conceptual knowledge which could be inferred from the placement and positioning of portals and objects on the submitted sketch. This also gave insight into participants reasoning abilities, and procedural knowledge in terms of justification and selection of communication procedure and whether the participant saw fit to include a pathway or methodology to inform the perceived player.
Participants were asked to complete as much of the computer simulation as they could from level 2 onwards with a 15 minute time constraint. The design of this task was to elicit detailed observations of participants' individual heuristics (type/selection/efficacy), level of reasoning abilities when problem-solving increasingly more difficult technological tasks. It was predicted that the time constraint would have a substantial effect on the type of individual heuristic employed ('Fast & Frugal' heuristics).

Participants

Participants volunteered to take part in the pilot study. Each was made aware that test scenario was to be recorded (video and audio capture); and that if they wished at any stage to opt out that they could do so (either individual task item or entire test scenario). The selection of participants was assessed under age, and school year. Subject selection was recorded for conjecture purposes.

Table 1: Pilot Participant details

Name:	Age:	Year	Gender	School type	Optional subjects
Participant A	12	1	Male	Secondary	Business Studies, Home Economics
Participant B	14	2	Male	Secondary	Materials Technology (Wood),Design, Craft & Art,
Participant C	13	2	Male	Vocational	Materials Technology (Wood), Technical Graphics Metalwork
Participant D	14	2	Male	Secondary	Materials Technology (Wood), Technical Graphics.

It was recognised that trend patterns would be unlikely to emerge; the focus of this pilot was to develop the capacity to track cognitive procedures of the participants and refine testing parameters with any discrepancy's found.

Data Collection & Analysis:

Middleton's [20]'Visual and Verbal Protocol Analysis' was employed when collecting and analysing data. Data was collected in two ways, first thinking aloud protocols described as thoughts that emerge and that are then verbalized. The second type of data was the video recordings of the participants' attempts at completing the technological task activities. Inferences of the problem-solving phase were identified from key points on the recordings; individual heuristics were also captured and identified on a retrospective/reactive observation which was aided from verbal explanations' or behavioural responses/expressions.

The data was collected from a number of different location settings; the main criterion was to mimic the school classroom environment with minimal distractions or interruptions for the participant and observer. The setting and timing of the pilot study was decided by the participants (home area) and testing was undertaken in the evening time for all of the participants.

Web-software was used to record participants' progression and decision making. The results of which were codified and categorized into a purpose designed '26 item Multidimensional Problem-solving Codex' (shown below in Table 2). The codex was designed to include individual heuristics that are associated with individual phases of the problem-solving cycle. The framework was designed to allow the researcher to categorize and track the use of individual heuristics separate to the recognised problem-solving cycle over a variety of generic tasks.

Table 2: Categories of Incidents of Cognitive Procedure codex

Phase	Index No.	Descriptor/Indicator
Identifying	1	Recognition Heuristic: focuses on recognised information/knowledge: excludes additional information
	2	Take-the-first (Heuristic)
	3	Effort and energy is put into establishing the given problem, constructing constraints, identifying components
	4	making sense of information in text, imagery, diagram, symbolism, signage, checking components in task
	5	Information is organised (verbally)
	6	Goals, parameters, constraints are represented by statements, pictorially (sketch, signage, etc.) and verbally
	7	Criteria/goals are established
Planning	8	Working Forward: Cycles from beginning of task through to end. (Heuristic)
	9	Working Backwards: Starts at end (constraint/objective) and works in reverse fashion. (Heuristic)
	10	Concepts, knowledge and facts are assessed and considered
	11	Various solution approaches are considered
	12	A conjecture/assumption is formulated
	13	Strategic development of solution approach(es) is (are) imagined
	14	Approach is determined.
Implementing	15	Means-ends analysis: combination of forward and backward thinking/reasoning. (Heuristic)
	16	Gaze Heuristic: focuses on path, process excludes additional information
	17	Selection and implementation of various procedures (movement with purpose, plan in action)
	18	Constructs (logically / illogically) connected statements.
	19	Carries out set process/procedure/ gives response (answer).
	20	Evidence of sense making/attempts to fit in new information with existing schemata/plan/process.
	21	Validation of conjecture is considered.
Evaluating	22	Generate & Test: reacting to outcome of process or conjecture. (Heuristic)
	23	Take-the -best. (Heuristic)
	24	Results are tested for their suitability/reasonableness.
	25	Decision is made about validity of procedure/answer/solution.
	26	Cycles back or cycles forward based on results from checking/critiquing.

The pilot study of the four participants highlighted the effectiveness of the codex to accurately record and highlight incidents of cognitive procedures (Shown in Figures 3 to 6). Two distinct forms of cognitive procedures were evident throughout the recording and graphing of results. The first was a fluid progression in use of the different cognitive procedures; this is represented on the scatter plot graphs as a continuous line. The second form was separate indicators of cognitive procedures. These are highlighted as specific and unconnected points on the graphs. This highlighted the divergent thinking skills of participants in action: that it recognises the alternation between fluid and disjointed thinking and reasoning skills employed in the participants during the problem-solving cyclical.

Secondly the sub-cycle of *conjecture, test*, and *evaluate (accept/reject)* method presented by Carlson and Bloom [3] was evident in the participants graphs in the later stages of the level progression task.

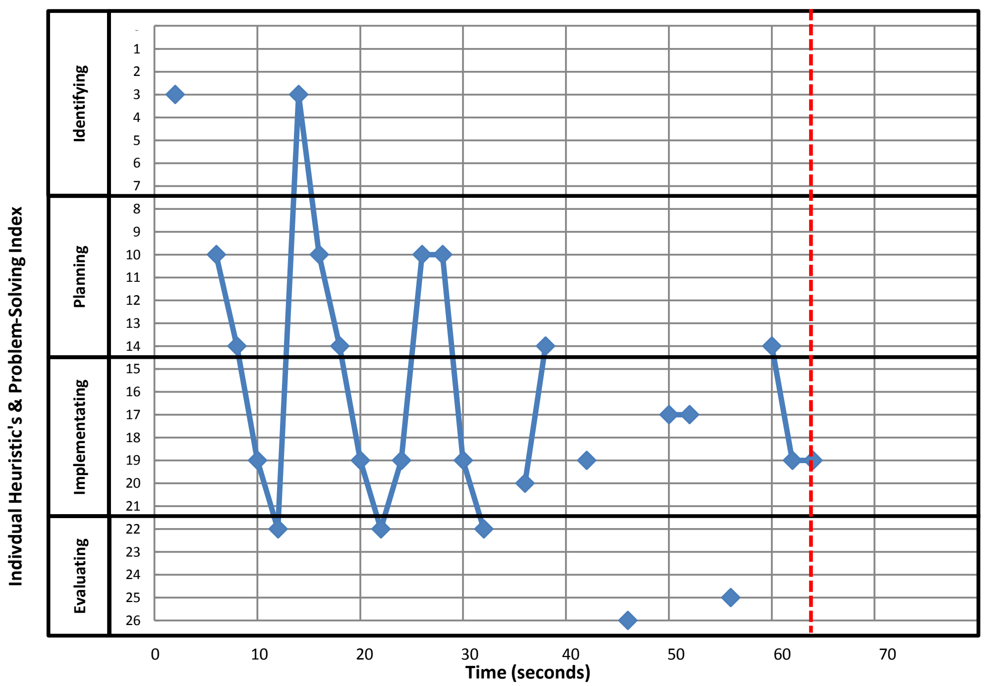

Figure 3: Participant A: Cognitive Procedures

The above figure details Participant A's successful attempt at completing the initial test. The task was completed in a quick time of sixty three seconds. The first half (30 seconds) of the activity sees the participant complete one full revolution of the problem-solving cycle; this was done in a determined and fluid motion. Problem area was determined early with the appropriate knowledge and procedures being effectively selected, implemented and assessed. The cycle shows that Participant A considered the concept and knowledge (item 10) after each generate and test heuristic (item 22). The second half of task activity sees the participant's cognitive procedures in a scattered formation: this was observed as the participant being reflective on the final critical steps on completing the initial test, ensuring that the process/plan is carried out correctly.
What can be inferred from this is the high level of abductive reasoning that the participant used in solving the initial task. The participant identified the two interactive items: the cube and pressure pad (participant's own words) in the room and then proceeded to test and manipulate both. He then adapted his perceived plan effectively to complete the test in a quick time frame.

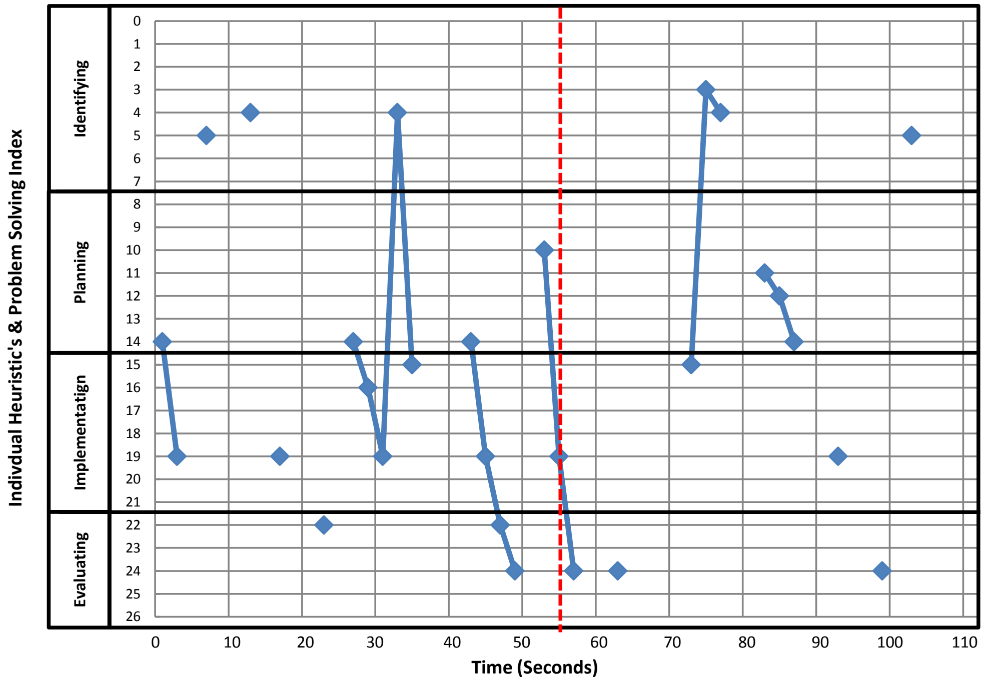

Figure 4: Participant B: Cognitive Procedures

Figure two above shows Participant B who, when compared to Participant A, took an opposite approach in problem-solving. The early stage of the initial test saw the participant take their time in establishing the correct problem area (from 0 to 25 seconds), after use of the 'generate and test' heuristic the participant them employed problem-solving cycle in sections of fluid motion. After completing the initial test the participant verbally reviewed the steps taken in completing the initial task.

Participant B was the quickest of all participants in the initial test and got the furthest in the third task item (level progression). The observations and evidence recorded in the pilot test highlighted Participant B's ability to recognise pattern formation in the game and to inductively reason when problem-solving the more difficult levels.

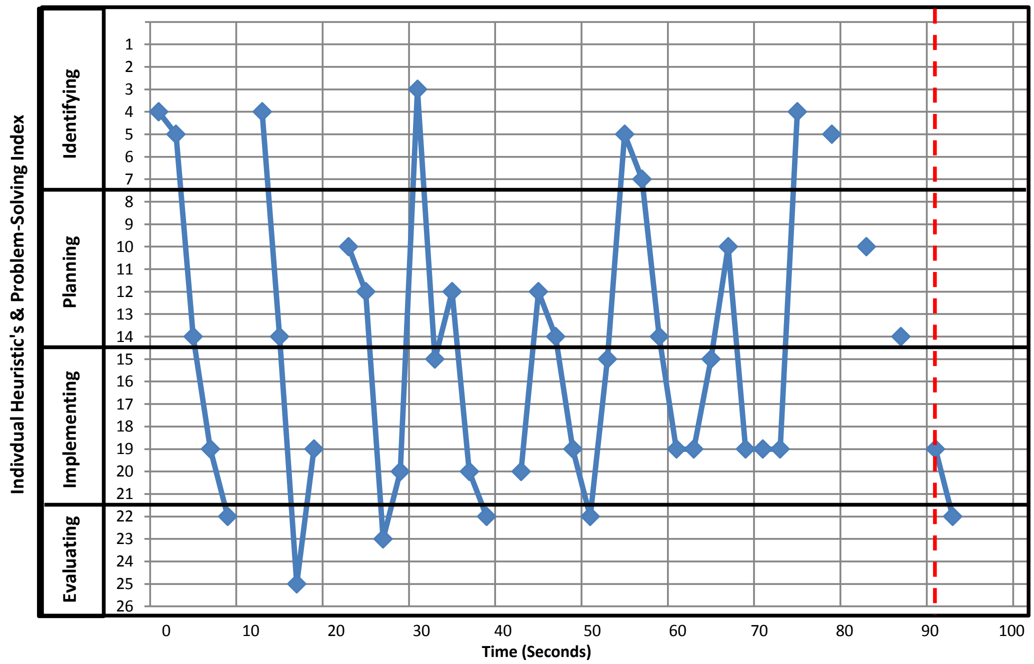

Figure 4: Participant C: Cognitive Procedures

Participant C proceeded to problem-solve in fluid motion through the problem-solving cycle. Figure 3 highlights that the participant's movement throughout the initial test was in a near continuous fluid motion. Observations recorded showed that at the participant continuously identifying, planning, implementing and evaluating until the correct solution was identified. Once the participant had obtained relevant information from the 'generate and test' heuristic then the participant's cognitive procedures employed became spread out, which highlighted the concentration of the participant's approach in completing the initial test and ensuring on a successful outcome.

The repetitive nature of the participant cycling through the problem-solving stages highlighted the development of understanding by being active throughout the test scenario. Each time the participant came across the unknown or problem area, the use of full problem-solving cycles were employed successfully. This highlighted the use and reliance of abductive reasoning in this initial test.

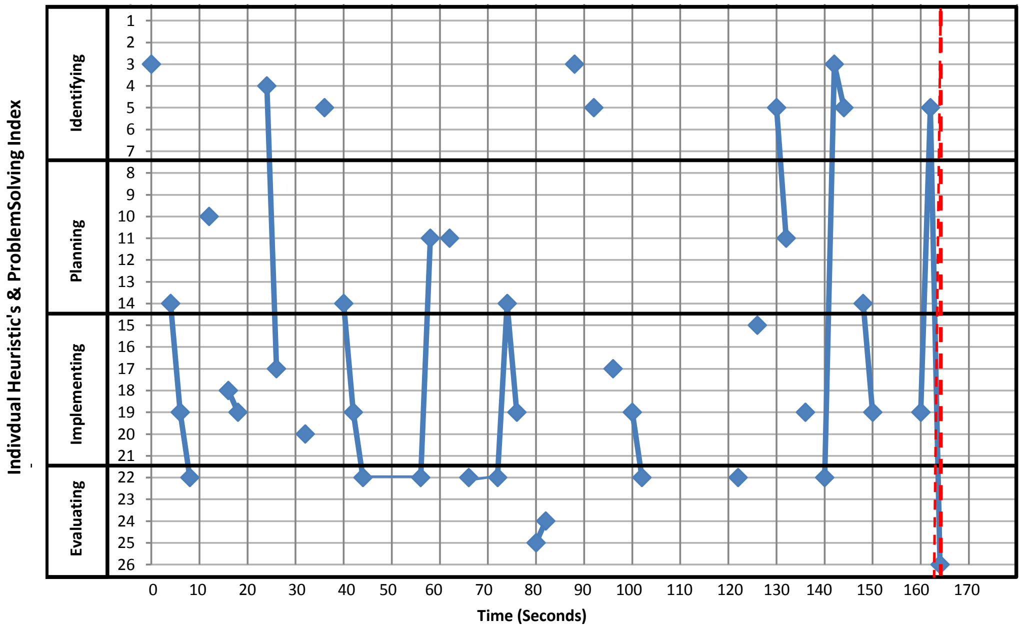

Figure 3: Participant D: Cognitive Procedures

Figure four above shows Participant D's progression and cognitive processes on completing the initial test. This was the longest attempt of the four participants'. The graph above highlights the participants attempts to work through the problem area without evaluating or identifying the outcomes of the 'generate and test heuristic' effectively (from 20 seconds to one minute 40 seconds). The participant continued to employ a tactic/process that did not produce desired outcomes; it was only through methodical movement and over reliance of 'generate and test heuristic' that the solution was eventually found.

While the participant did complete the initial test it highlighted the pupil's reliance on rote methods to complete tasks without the formation and development of understanding when undertaking a task (not necessarily technological in nature). The concern is that the participant's 'search rule, stopping rule, and decision rule' making as highlighted by Rabb & Gigerenzer [19] has not been addressed by the participant. This would then infer that the participant relies mainly on deductive reasoning skills.

Discussion:

While the paper is focused on a small number (as part of a larger study), there was no apparent connection between age or subject selection in the success rate of problem-solving or reasoning abilities. The relevance of this paper with regards to the teaching of design at third level is the relationship between design and problem-solving is similar to that of technological capability and technological literacy; i.e. both are separate but have core similarities. The skills, knowledge and abilities developed at early second level are the foundations to what pupils' will use and develop at third level and beyond.

When comparing all four participants initial test results four distinct characteristics in problem-solving abilities is clearly highlighted, while the size of the pilot test is small it is envisaged that certain trends will be highlighted similar to that produced in the pilot scores. The use and implementation of the various cognitive procedures gave insight into the level of reasoning that participants produced. Participant B was the only participant who was able to inductively reason in the later test (level progression) and as a result got the furthest of all participants (level four). Participant A and C highlighted incidents of abductive reasoning throughout test parameters. This resulted in both participants failing to progress past the same problem area in the computer simulation (level four). There was clear evidence of fixation on both participants' problem-solving strategies

Participant D failed to progress past level three. The problem-solving strategy that he employed in the first computer simulation was repeated in the following level, but failed him on in the third level. A key point to note was that out of the four participants, participant D was the only person not to evaluate/critique how he succeeded at the end of the level. It highlights the concern of educators with regards to pupils learning (or completing work) through rote methods and it will be of interest to see from the full study as to the number of pupils that rely on these type methods and the range of tasks that they apply it to.

There was evidence of the relationship between reasoning, communication (verbal and graphical) and pattern recognition of the various problem areas in the totality of the test area. Participant B was the most successful in level progression and the solution produced in the second task highlighted a level of spacial awareness and inductive reasoning abilities that the other participants did not possess. Certain behavioural types were clearly evident from reviewing participants' cognitive procedures. It highlighted the divergent nature of the technological task as well as the divergent behaviours of participants in this group. It will be of interest to see if participants will achieve a similar result in the other four test areas and if the same problem-solving strategy is employed.

The most selected heuristics throughout the computer simulation was the generate and test heuristics. It was found in the second test that means analysis heuristic was the most employed, which infers that the nature of the task impacts dramatically on the selection and reliability of heuristics, and problem-solving strategies.

Conclusion:

Even though this was a pilot study on a small number of participants the effectiveness of the 'Visual verbal protocol' was effective in reliably recording incidents of cognitive procedures, behaviours and abilities of participants. The range of heuristics used was limited when observing the participants attempts; it will be of interest to see if this range rises significantly in the complete battery of tasks are implemented.

The results highlighting the different problem-solving behaviours is promising; as it gave more insight into possible trends that pupils in this age bracket may possess than was first envisioned by the author.

It also raised the question as to future participants' results across the battery of tests (five themes based on the key aspects of technological capability). Will they improve over the range of tasks or will they (individually) stick rigidly to problem-solving strategies that already possess? And, if so, what effect does subject selection play in maintaining or addressing these issues?

1. Gibson, K., *Technology and technological knowledge: a challenge for school curricula.* Teachers and Teaching, 2008. **14**(1): p. pages 3 -15.
2. Ingerman, Å. and B. Collier-Reed, *Technological literacy reconsidered: a model for enactment.* International journal of Technology and Design Education, 2010: p. 1-12.
3. Carlson, M.P. and I. Bloom, *The cyclic nature of problem solving: An emergent multidimensional problem-solving framework*. Educational Studies in Mathematics. Vol. 58. 2005: Springer. 45-75.
4. NCCA, *BOARD OF STUDIES FOR THE REVIEW OF TECHNOLOGY EDUCATION IN THE JUNIOR CYCLE: Final Report*. 2004.
5. McGuinness , S.C., L. O'Regan, F., *An Evaluation of the Implementation of Technology in the Junior Cycle Curriculum*, F.O.R. L Corcoran, Editor. 1997, Trinity College: Dublin. p. 124.
6. Ning, Y., Z. Fan, and B. Feng, *Knowledge Capability: A Definition and Research Model.* Knowledge Science, Engineering and Management, 2006: p. 330-340.
7. Kimbell, R., *Tackling technological tasks.* Practical Science, 1991.
8. Kimbell, R. and K. Stables, *Researching Design Learning*. 2008: Springer.
9. Morley, J., *1 The challenge for design and technology education*. Issues in Design and Technology Teaching, ed. J.M. Su Sayers, and Bob Barnes. 2004: Routledge. 1.
10. Doherty, P., et al., *Planning for capability and progression for design and technology in the National Curriculum.* Teaching technology, 1993: p. 111.
11. Black, P. and G. Harrison, *Technological capability*. 2nd ed. Teaching Technology, ed. B. F. 1994, London: Routhledge.
12. Lesh, R.Z., . J, *Problem-Solving and Modelling*, in *Second Handbook of Research on Mathematics Teaching and Learning*, F. Lester, Editor. 2007.
13. Sternberg, R.J., J. Mio, and J.S. Mio, *Cognitive psychology*. 2009: Wadsworth Pub Co.
14. Myer, G.D., *Psychology*, ed. C. Woods. 1980, Michigan: Holland College.
15. Polya, G., *How to solve it*. 2008: Princeton University Press.
16. Gigerenzer, G. and W. Gaissmaier, *Heuristic decision making.* Annual review of psychology, 2011. **62**: p. 451-482.
17. Todd, P.M. and G. Gigerenzer, *Précis of simple heuristics that make us smart.* Behavioral and brain sciences, 2000. **23**(5): p. 727-741.
18. Shah, A.K. and D.M. Oppenheimer, *Heuristics made easy: An effort-reduction framework.* Psychological Bulletin, 2008. **134**(2): p. 207.
19. Raab, M. and G. Gigerenzer, *Intelligence as smart heuristics.* Cognition and intelligence, 2005: p. 188-207.
20. Middleton, H.E., *Examining design thinking: Visual and verbal protocol analysis.* Researching technology education: Methods and techniques, 2011.