DO ENGINEERING STUDENTS FROM VOCATIONAL AND ACADEMIC BACKGROUNDS THINK DIFFERENTLY?

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ABSTRACT

This work describes an experimental study to try to better understand the natural and previously evolved problem solving strategies used by entrants to undergraduate engineering programmes. New entrants to degree and pre-degree programmes were presented with a range of brain-teaser and practical problems requiring no specific prior knowledge to answer. Some would have unique answers with others being more open ended. Students worked in pairs to solve the problems and their discussions, notes and where relevant physical interactions with props were recorded and observed. The results were then coded and conclusions drawn based on both general approaches and whether particular types of student educational backgrounds influenced their approaches to problem solving.

KEYWORDS

Problem solving, entry standards, qualifications, experimental. Standards: 4, 5, 8, 12

INTRODUCTION

This research is to determine the natural tendencies in numerical and visual logic type problem solving of new entrant students to degrees in engineering.

The aim is to establish if there is a difference in the way students in the English educational system think and learn in these types of problems and whether there is a notable difference between those entering from an academic (typically A-Levels) or vocational (BTEC) route. This type of problem solving is often key to becoming an effective practical engineer and will help us better understand student preferences and diversity in approach to tackling these problems, so helping us better develop engineering problem solving in our students.

While A-level students are still dominant, students with BTECs or a BTEC combined with an A-level are becoming increasingly common at University entry and make up a significant part of entry cohorts in many institutions particularly those with low to middle level entry tariffs. The uptake of students taking BTECs has grown dramatically over the last decade growing from 50,000 to 150,000 between 2006 and 2014 (Richards 2016). For the 2016 application cycle 54% of students accepted onto a University course nationally held only A-levels with 18% holding only BTECs and a further 8% holding a combination of the two. (Gicheva N, Petrie K, (2018), Havergal, C., (2016)) It should also be noted that there are notable socio-economic differences in the characteristics of many students taking vocational over academic qualifications with factors such as parental occupations and historic participation of the community in University education also linked to choice of qualification taken.

Students being offered places at University nationally are more likely to have done so via vocational qualifications if they have come from low participation areas or their parents have manual rather than professional occupations. (Gicheva N, Petrie K, 2018). Similar indicators can also be found for the greater likelihood of vocational qualifications among students receiving free school meals, a common proxy for low income family background (Richards (2016)). Related to this are concerns that students entering University with vocational qualifications, even if nominally equivalent in tariff to their academic counterparts, very noticeably do not perform so well once on their degree, whether due to syllabus mismatch, learning and assessment modes, preparation, perception of self, or socio-economic factors. (Shields, R & Masardo, A, (2018), HEFCE (2018), Gill T., (2018)).

In the engineering field much of the focus of this transition gap has focussed on conventional academic deficiencies, most notably mathematics (Gallimore & Stewart (2014)), however we are also keen to formally investigate to see if there are differences in the way students think about and tackle more applied visual and practical problems. Problem solving is a key aspect of becoming an engineer and much has been written on it in relation to students own understanding of the role of problem solving ((Kim (2018), McNeill et al. (2017), Koro-Ljunberg (2016)), placing the work in context (Wolff (2017)), categorization of problems (Scheulke-Leech et.al. (2020)), competence of graduates (Clegg (2019 et.al))Burkholder et.al. 2021) and so on.

The overall methodology used here will be a meta-analysis making use of existing literature, historical data of the performance of students on different module types, interviews and experimental observations. These will then be analysed to draw up proposals to support vocational and academic entrants which will be trialled, and the outcomes disseminated as advice, guidelines and best practice. The focus of the work presented here is however the experimental work.

METHODOLOGY

The approach here involves a mix of problem solving observations and questionnaires with students on the first year or foundation year of engineering degree programmes at an English University.

Participants

Students were asked to volunteer via open calls in classes hosting students on relevant programmes and those taking part in the work were provided with a ‘thank you’ in the form of a shopping voucher in return for participation. Participant responses to questionnaires and problem solving exercises were anonymized at start of participation.

Ethical approval

The research approach and the use of the volunteers was approved via the Aston University ethics committee (Ref. 1550).

Questionnaires

The questionnaires were used to determine the demographics and educational background of the individuals and their perceived preferences when solving problems or on confidence levels when solving particular types of problem eg.

“I like to draw diagrams to help me progress toward a solution” (agree-disagree Lickert scale)

“On a 1-5 scale with 1 being least confident and 5 being most confident, how confident would you feel answering the following types of problems ?

- Estimation (eg. number of bricks to build a shed to within 20%)
- Optimisation (eg. working out whether best to buy or rent)”

Problem Solving Exercises

Students were paired together to solve practical problems. Pairing was used to help encourage verbalization of ideas and approaches to solving the problems, so enabling recording of the methods used. Pairings were set up based on student availability for a given session and where possible those with similar pre-University qualifications were paired up.

Problem sessions were of a nominal two hours with around 90 minutes spent on activity and the remainder explanations and formalities. Sessions were video recorded with the focus of the camera on the workspace, avoiding student faces to retain anonymity. Participants would attend up to two sessions with different problems presented in each session.

The aim of the exercise was to look at problem solving methodologies rather than technical knowledge and given the participants were new students, each problem was designed such that there would be no specific engineering or scientific prerequisite knowledge though basic high school arithmetic, trigonometry and algebra skills would be assumed.

A range of problems were presented, covering a variety of different challenge types. For example :

- Logic problems – eg. determine the correct combination of terms to be compatible with a set of verbal expressions.
- Visual problems – eg. Fitting tiles into a particular shape
- Open problems – eg. design a concept to solve a practical problem
- ‘Out of the box’ problems – eg. problems with a non-apparent approach

Problems were generally designed to be able to be achieved in in around 15 minutes. If students were unable to complete these in the time allotted the tests would move on to the next problem.

Students were also provided with large sheets of paper to work on and these were recovered following the tests to help understand the approaches used. Students were also allowed to use calculators if they felt it might help in some problems. Certain problems also featured physical props – such as tiles or blocks - which could be used as part of the problem solving.

Post testing

To help with analysis of the problem solving approaches a coding system was used to record the content of the videos and the approaches to problem solving in a systematic manner. Table 1 describes this coding.

Also recorded will be any tools used to help visualise or support solving the problem:

- Numerical / Algebraic Model: NM
- Graphics - Sketch / Drawing: GR
- Artefacts – provided (tools, components, blocks etc): AP
- Artefacts – improvised (pen tops, erasers, components used abstractly): AI

Table 1 . Coding structure for recording approaches used

CODE	DESCRIPTION	VERBAL EXEMPLAR TO TRIGGER CODING (typical expressions - physical and graphical equivalents also permissible)
Clarifying (clr)	Clarifying initial problem or current state of solution	"So the key thing is…" "We are limited in how much…" "…is important but *that* is not…"
Exploring / proposing (exp)	Generating (and selecting) possible pathways for solution	"Can we brainstorm…" "How about *this* or *that*…" "We could…."
Trialling (tri)	Testing suppositions, physically, numerically or otherwise	"Could we play around to see if…." "So we should be able to…." "Can we see if we can add these up it should give…"
Progressing (prg)	Following a logic step wise path toward particular solution stage	"If we can first work out…" "Now we know *this* then we can …."
Questioning (que)	Checking and quearying proposal	"Are we sure it would be strong enough?" "Are we missing something ?"
Adapting (ada)	Modifying a solution stage which is seen to be promising if not fully appropriate	"If we changed this…" "Rather than……how about….."
Retracing (rtr)	Going back to last assumed 'good' state	"So we are confident up to here…?" "If we go back to…."
Abandoning (abd)	Abandoning possible pathway	"This isn't going to work"
Presenting (prs)	Confirmation and presentation of proposed solution	"I think we've got it…" "Just checking but looks good…"

ANALYSIS

Figure 1 shows a graphical representation of the questionnaire results in which self-reported problem-solving strategies were explored. The students were responding on a five-point Likert scale covering the sort of methods or tools students felt helped them to solve problems.

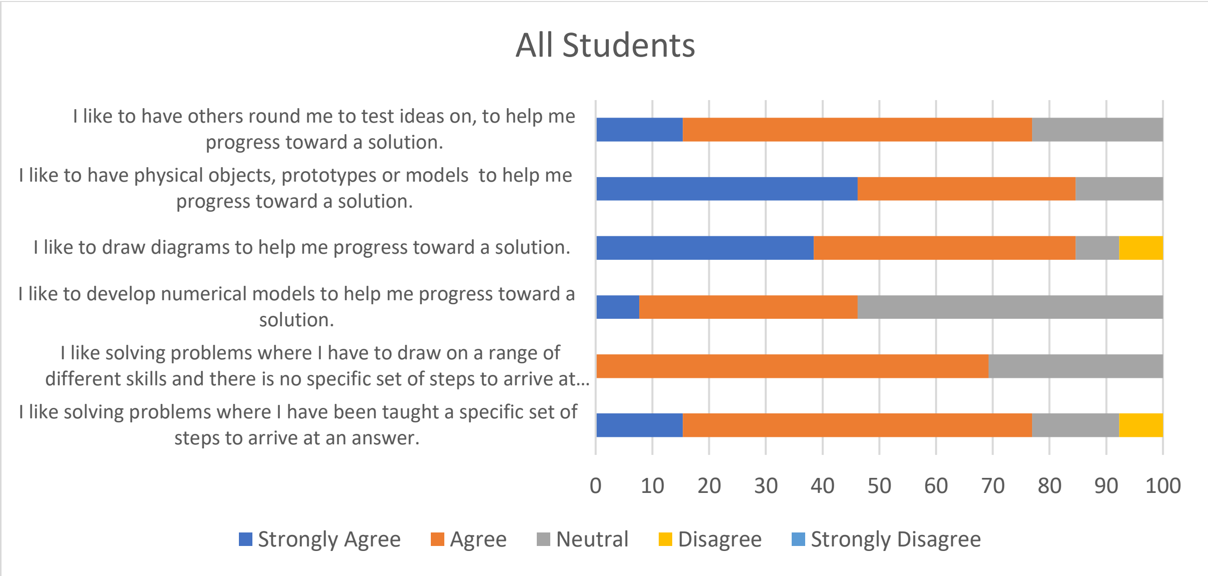


Figure 1 : Student's declared preferences in problem solving

Splitting some of the questions into those from A-level and from less traditional routes showed some differences (Figures 2 & 3).

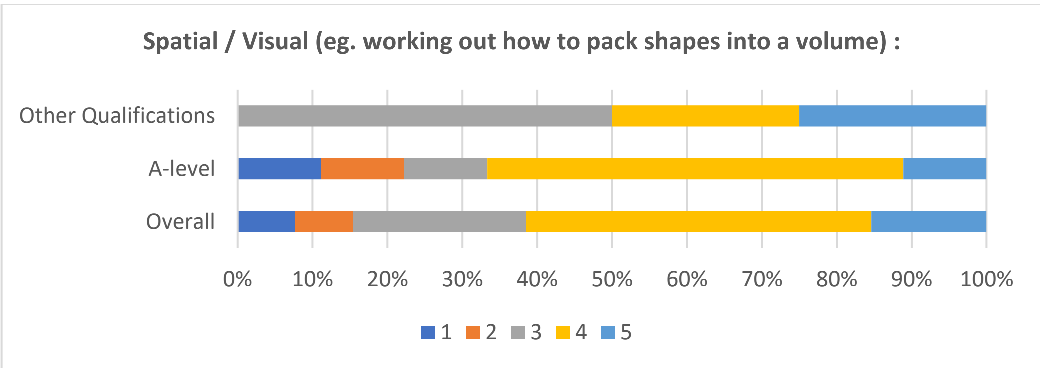


Figure 2: Student Confidence Levels for Spatial / Visual Problems – 1=Low, 5-High

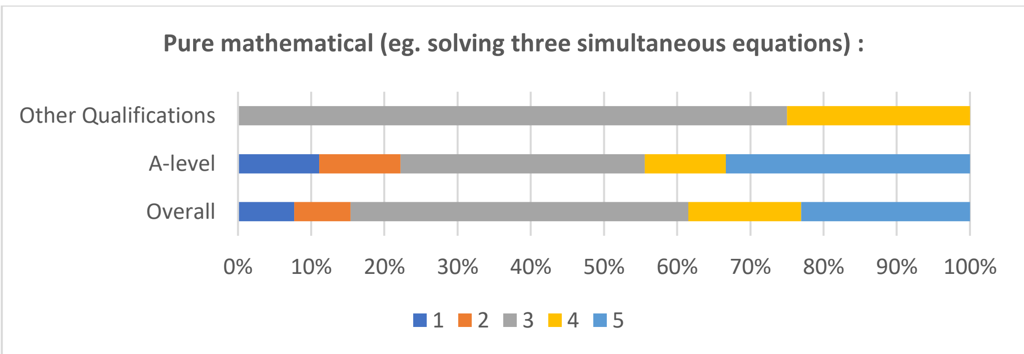


Figure 3: Student Confidence Levels for Mathematical Problems – 1=Low, 5=High

The results from the practical problem-solving trials were rich and are likely to require significant further review to fully draw out the learning which can be gained from these. Logic problems and those with a definite leaning to needing some form of undefined mathematical approach seemed to prove the most problematic for students to grasp and self-develop a strategy.

By contrast those with visual elements seemed to give students more to grasp and even where the approach used may not have been optimum, students seemed to be more willing to keep trying and were less likely to hit a dead end.

A number of problems were designed to have non-obvious and indirect solutions – eg. An apparent 2d problem which could only be solved by using 3d methods and this ‘out of the box’ type thinking stumped many unless prompted with clues as to the approaches used though neither group of students seemed more favoured by these types of challenges.

Some problems were couched as mini design challenges eg. – “Come up with 3 concepts to help doctors safely extract sweetcorn from childrens’ ears” and so had no fixed solution. Students tended to tackle these problems with confidence, though as might be expected not necessarily following a process or critical review of the concepts. While most categories of problem showed little difference between the student types, these problems seemed to particularly appeal to those from vocational backgrounds.

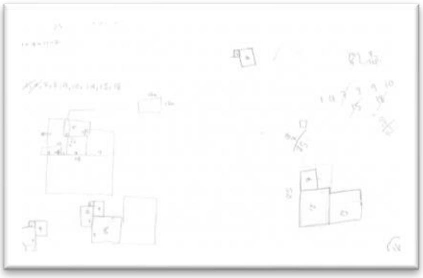
Practical Problem Solving Example: Carpet Fitting – Spatial Geometry

In this problem students were given a list of carpet tile sections ranging from 1m x 1m up to 18m x 18m and asked to join these to create a perfect rectangular shape using all the sections and with no overlaps, gaps or protrusions. Initially students were not provided with any physical tiles to work with, nor were they told these would be provided at some stage.

With the physical tiles to hand this can lead to a simple case of manual assembly and trial and error and would preclude any other options.

There is however potential for some logic and mathematical approaches to help support the decision-making process in this problem though not all groups identified this. Primarily the realisation that the area of the carpet elements will be the same as the assembled rectangle. In addition, groups should generally identify that the shortest side must exceed the size of the largest tile (18m x 18m) and that only certain combinations of widths and breadths will match the total area. This then gives a potential tool to identify how the tiles could combine to give these dimensions.

Figures 4 & 5 show exemplar results from a couple of the student trials on this problem. In this case the students in Group 14, 16 came through a traditional A-level entry route, while students in Group 1,2 had a broader educational background.

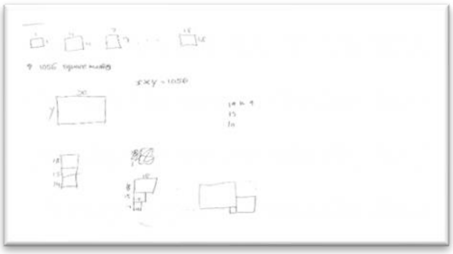
 

Exemplar Trial Record Following Transcription and Coding

Date : 26.01.22
Location : LG36
Problem set : TileFitting
Participants : 14,16
File : C:\Users\thomsoga\Desktop\Trial Data\220126-14-16\SUNP007
File : C:\Users\thomsoga\Desktop\Trial Data\220126-14-16\SUNP008

Time		Code	Tool	Notes
14:44:50		CLR		Problem sheet issued - read through
14:45:36	00:00:46	CLR		Tutor clarification
14:49:30	00:03:54	PRG	paper	start with one - some attempt at logical progression
14:50:40	00:01:10	PRG	paper	Some use of maths "even number needed" - drawing out
14:52:00	00:01:20	TRI	tiles	tiles released
14:53:08	00:01:08	TRI	tiles	playing with tiles but trying to add values
14:54:56	00:01:48	PRE		presenting and checking
	00:10:06			

Figure 4 : Group 14,16 (A-level background) video still, working sheet and encoded process sheet for the carpet tile fitting problem

Exemplar Trial Record Following Transcription and Coding

Date : 21.12.21
Location : LG36
Problem set : TileFitting
Participants : 1,2
C:\Users\thomsoga\Desktop\Trial Data\211221-01-02\SUNP003

Time		Code	Tool	Notes
11:05:37		CLR		Clarification of Problem - largely silent, no writing or sketching
11:06:56	00:01:19	CLR		Tutor clarification,
11:08:10	00:01:14	PRG	Calc	Total area calculation
11:09:23	00:01:13	TRI		Trying to determine next step
11:10:00	00:00:37	TRI/PRG		Realisation that need whole numbered sides to give area of combined rectangle "So if width is 18, length is 58. something, something, so let's try...."
11:11:21	00:01:21	PRG		Tring to find combinations of tiles to meet values
11:13:57	00:02:36	PRG		Continuing to trial combinations
11:16:31	00:02:34	TRI	Paper	Sketching out ideas
11:17:40	00:01:09	TRI	Tiles	Tiles issued
11:18:50	00:01:10	TRI	Tiles	"It's not going to work" - using tiles to trial options
11:23:16	00:04:26	PRE	Tiles	"That is it"
	00:17:39			

Figure 5 : Group 1, 2 (Mixed background) video still, working sheet and encoded process sheet for the carpet tile fitting problem

In this case, as with many of the problems, the two student groups appeared to follow similar processes regardless of student background. Group 1, 2 picked up on the fixed area constraint early on and appeared to follow a more logical approach. Group 14, 16 appeared slower to pick up on this issue and did make extensive use of sketching to help flesh out their ideas.

DISCUSSION & CONCLUSIONS

It has to be recognized that the activities and problems set were relatively small scale – 15 minutes typically, and so not necessarily the complex, multi-dimensional problems they will have to tackle in the future while the number of students involved was modest. This and the fact that students were not being asked to use formal engineering knowledge or skills due to by nature being focused on untrained entrant students means it does not necessarily correlate to those students later in their education or careers.

This work has highlighted however some of the key factors in the approach of engineering students to problem solving.

With physical problems we seemed to observe an eagerness to get involved though a goal focused approach tended to mean a drive to deliver a solution early, often through trial and error, rather than perhaps reframing the problem early to eliminate options and give direction to the solution route.

Logic type problems can often require a systematic approach – having a structured method to hone in on an answer by continually tightening the goal requirements through analysis of the data and eliminating those options which do not meet these. Keeping track of both the tightening specification and the list of options was not always done and not always in harmony.

Problem solving is and is likely to always be a key part of an engineer's skill set and the engineer needs to be able to apply a range of strategies to solve a diverse variety of problems. Understanding how to build on the latent capabilities of students to solve problems while offering workable and practical support to develop strategies to optimize their ability to develop viable solutions is a key skill of graduate engineers and a key area for educators to work on to support their students.

Some recommendations which come from this work are as follows:

- The work shows students on engineering programmes want to solve problems and capability in this is independent of background. Therefore, ensure all students and in particular those from a vocational background are fully supported in all aspects of their degree and scrutinise carefully syllabi to ensure hurdles are not placed unnecessarily – eg. Complex engineering science or mathematical theory taught but then never used elsewhere in the curriculum. Without this type of thinking we risk losing highly capable problem solvers from the discipline.

- Encourage students and support students to use the problem-solving approaches which suit them best but ensure opportunities are given to explore other methods as their underpinning skill sets evolve and the problems and projects they work on become more complex.

- Consider incorporating short form, non-linear problems into the element of the curriculum to support and stimulate creative solution finding among students beyond the long form major complex projects.

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