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What Do We Know About Our First-Year Engineering Students' Backgrounds And Experiences?

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What do we know about our first-year engineering students' backgrounds and experiences?

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ABSTRACT

Students entering university come from a wide variety of backgrounds and experiences, with differing levels of knowledge and exposure to professional skills. However, university entry criteria typically focus on academic ability in particular subject areas such as maths and physics, but little information is known about students' attitudes and abilities in a variety of other, important domains such as attitude towards engineering, communication skills and level of interaction with peers. Self-concept, a cognitive evaluation that an individual makes and customarily maintains with respect to themselves concerning their ability in a general or a specific area of knowledge, can be used to evaluate students' perception of their attitudes and abilities across these previously unmeasured domains for academics to better understand the composition of the first-year student cohort.

In this paper, results of surveying approximately 350 first-year engineering students' self-concept across several distinct domains are reported. Exploratory factor analysis was performed on the resulting data, yielding 8 composite factors comprising of a mix of the original domains. While students strongly associated academic ability with perceived skill in mathematics, there was a surprising pair of engineering factors that emerged – one that captures 'engineering affect' and one that captures students' perceived relationship between engineering and creativity. It was also found that self-concept in peer interaction and communication skills were lowest out of the 8 identified factors. The results will be used to develop activities and programs to suit students' needs, particularly in terms of improving peer interaction and communication skills.

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1 INTRODUCTION

Traditional entry requirements for engineering degrees focus on academic achievement in high school and the prior attainment of specialised knowledge in areas such as mathematics and the physical sciences. These requirements are often listed in terms of overall minimum percentile results or aggregate subject scores and the requirement that a certain amount of discipline specific units have been completed. Some degree programs also utilise entrance exams to ensure that students pursuing a given degree have mastered foundational concepts required for that program (Basavaraj et al. 2021). What these entry requirements do not reveal, however, is an understanding of the diverse backgrounds, experiences, and skill sets of engineering students. In an environment that is placing an increasing focus on the development of professional skills such as communication and problem-solving skills in engineering students (Nair et al. 2009), it is crucial to capture an understanding of students' perception of their level of these skills when they commence their degree and have mechanisms in place to track their development over time. Furthermore, there is a lack of vision of commencing students' attitudes towards learning, their sense of overall academic ability and concept of engineering. Note that these attitudes are distinct from the foundational discipline knowledge assessed through traditional entry mechanisms yet are crucial to understand, particularly in introductory engineering courses that are key to retention in engineering.

Self-concept, a psychological construct that refers to an individual's overall perception and evaluation of themselves, is a vital tool for assessing students' perceptions of their attitudes and abilities across these previously unmeasured domains (Gable 1986; Shavelson et al. 1976). A comprehensive understanding of students' self-concept can help educators better support their learning and development throughout their engineering education. To this end, this paper outlines the authors' approach to measure first-year students' self-concept across a number of important domains such as academic ability, communication skills and engineering self-concept. By undertaking this study, the authors sought to identify patterns and trends in students' self-concept that could inform the development of targeted activities and programs and cater to the diversity of student experience and self-concept, promoting a more inclusive and effective approach to their engineering education.

This study was conducted at the University of Melbourne, a leading university in Australia, where students complete a 3-year undergraduate Bachelor of Science degree followed by a specialist 2-year Engineering Masters degree, commonly referred to as a '3+2 model'. Participants of the study were sourced from a first-year general engineering course within the Bachelor of Science, which serves as a gateway to further engineering study in later years. Student experience and skill development in the course is vital for retention in engineering as students do not need to choose their major until the second year of their degree. Given a poor experience in the course, students may choose to drop out of Engineering and pursue another science major such as Physics, Chemistry or Computer Science. Additionally, with such a generalist first year, students come from a wide range of backgrounds and experiences, which has implications for ensuring equity within student project-teams. A mix of international and local students enrol in the course which further adds to the diversity of the first-year cohort.

This paper will introduce the notion and importance of assessing student self-concept and describe the development of the survey instrument. The results of conducting the survey on 350 commencing first-year engineering students will be presented and analysed. The paper will conclude with a discussion highlighting the key features of the analysis and what implications these might have on the development of student learning activities into the future.

2 METHODOLOGY

Self-concept is defined as a "cognitive evaluation that an individual makes and customarily maintains with respect to themselves concerning their ability in a general or a specific area of knowledge" (Gable 1986; Shavelson, Hubner, and Stanton 1976). It is a hypothetical construct, and has been identified as a contributing component in expectancy models of motivation, which are based on the notion that individuals will choose, and persist in doing, a task if they have a reasonable expectation for success (Pintrich and Schunk 1996). It has also been observed that academic self-concept has motivational properties such that changes in academic self-concept will lead to changes in subsequent academic achievement (Marsh and Yeung 1997).

Multiple instruments for assessing self-concept have been developed over the years that can be used with individuals from childhood through to late adulthood and have varying levels of psychometric soundness, the strength of their theoretical base, and utility in a variety of research and practice situations (Byrne 1996). The Self-Description Questionnaire III (SDQIII) (Marsh and O'Neill 1984) was originally developed for assessing self-concept in high-school students and has proven strong validity and reliability characteristics (Wylie 1989; Marsh and Shavelson 1985; Marsh 1990). The SDQIII defines 13 factors (e.g. mathematics, verbal, academic, relations with peers, physical appearance) to measure self-concept that are assessed using a 136-item questionnaire. It is not tied to a specific domain, unlike some other self-concept instruments, and as such was deemed to be an appropriate basis for developing an instrument to assess the self-concept of first-year engineering students at The University of Melbourne.

In order to assess students' self-concept, the SDQIII was adapted for first-year engineering students in the following way:

- Five of the factors were adapted directly from the SDQIII: Mathematics (M), Academic (A), Creativity / Problem Solving (Pr), General Self-concept (G) and Honesty (H);
- A factor pertaining to Engineering (E) was created by modifying several of the SDQIII 'Mathematics' items to relate to engineering;
- A factor on Communication Skills (C) was created by modifying SDQIII items representing the 'Verbal' factor to more broadly cover communication skills, involving both written and verbal communication which are both essential for engineering students;

- A factor on Peer Relationships and Interactions (Pe) was created by adapting items from the SDQIII ‘Relations with Same Sex Peers’ factor, as teamwork plays an important part in first-year and subsequent engineering courses.

Ten survey items were taken or adapted from the SDQIII for each of these eight factors that were deemed most appropriate for understanding self-concept with respect to first-year engineering students. All up, there were a total of eighty items on the survey instrument and these were placed on the survey as statements in a pattern similar to that of the SDQIII – every eighth item belonged to the same subscale and items were randomly distributed by direction (positive or negative). This structure ensured that the items on the subscales were psychometrically distinct yet had strong internal consistency. A survey form was generated that asked students to rate how accurately each statement (item) described themselves and were provided with a seven-point scale ranging from “very inaccurate” to “very accurate” to perform this rating. It was decided to provide seven choices to help strengthen the reliability of the instrument and allow greater distinctions between responses (Gable 1986).

3 RESULTS

The self-concept survey instrument was administered to commencing Bachelor of Science students during scheduled class time. Students were given approximately 15 minutes to individually complete the paper-based questionnaire under exam-like conditions. All survey data were collected anonymously and students could elect to not participate in the survey by not submitting their survey to the facilitators. Overall, 350 students took part in the survey, with 294 students returning surveys to be included in the analysis, which were scanned and processed by a machine-reading program. Of these 294 surveys, 286 contained complete results and these were used as the basis of the analysis. The five most accurate and five least accurate statements, measured by the means of the item responses, are given in Table 1.

Table 1. Survey items with the strongest responses

Most accurate statements	**Mean**	**Std. Dev**
14. I am comfortable talking to other students	5.56	1.30
20. I find engineering concepts interesting and challenging	5.53	1.18
27. I enjoy working out new ways of solving problems	5.37	1.24
56. I am a very honest person	5.34	1.30
32. I nearly always tell the truth	5.33	1.37
Least accurate statements	**Mean**	**Std. Dev**
4. I have never been excited about engineering	2.21	1.26
24. Being honest is not particularly important to me	2.28	1.45
22. I don't get along very well with other students	2.3	1.24
9. I have hesitated to take courses that involve mathematics	2.42	1.59
69. In school I had more trouble learning to read than most other students	2.51	1.63

From these results it is noted that, overall, students have a strong interest in engineering concepts and enjoy solving problems in new ways. This is perhaps not surprising as the university typically attracts high-achieving students. Furthermore, Q20, Q27 and Q4 were amongst the survey items with the lowest standard deviations, indicating a level of uniformity in this sentiment. It is interesting to note that questions relating to Honesty and Peer Interaction also figure prominently in the strongest responses, potentially indicating a student body that appears to have a strong sense of integrity and personability.

Based on the instrument's original eight factors, average response values (normalised to 100%) for each could be determined across all respondents, noting that items on the survey instrument that had a negative direction were inverted on the scale. Mathematics, Engineering, and Honesty rated highest (71%, 70% and 72% respectively), while Communication Skills, Peer Relationships and Interactions, and Problem Solving rated lowest on average (67%, 66% and 66% respectively).

Overall, a composite total self-concept rating, out of 7, could be obtained via averaging results for all items for each student and then taking the average over all students. This revealed that:

- 43.9% of students rated themselves having strongly positive overall self-concept (greater than or equal to 5)
- 55.0% of students rated themselves having overall neutral self-concept (between 3 and 5)
- 1.1% of students rated themselves having negative overall self-concept (less than or equal to 3)

The original eight factors were selected to assess self-concept over dimensions deemed important for first-year engineering students. However, students were not explicitly told what these factors were, and thus further analysis was performed to indicate if survey items had similarity in patterns of responses by students and whether they mirrored the underlying factors. *Exploratory factor analysis* was used as a statistical technique to determine how particular items could be grouped together to define new, constructed *subscales* (Fabrigar et al. 1999). This was an iterative process, in that several analyses were needed to be run, each with different constraints, and then the results evaluated for interpretability. A more detailed discussion of the procedures available and the decision making process involved can be found in standard texts (Gorsuch 1983). All statistical analyses were performed using IBM's SPSS software package, version 28.

The matrix of simple correlations among the survey items contained a reasonable number of values in the range 0.3 to 0.7 with significance (2-tailed) less than 0.001, indicating the likelihood that the data set would likely factor well. To formally assess this, the Kaiser–Meyer–Olin (KMO) measure of sampling adequacy, which compares observed correlation coefficients with partial correlation coefficients, was calculated as 0.86. Kaiser (1974) recommends a minimum barely acceptable KMO value of 0.5, values between 0.7-0.8 as acceptable, and values above 0.9 as superb.

Factors were extracted using the *principal components analysis* method. A scree plot of eigenvalues and observation of the amount of variance explained by each one indicated between 7-8 strong factors. There was a clear break observed in the scree plot between the eighth and ninth eigenvalues, indicating a sensible choice of eight factors to extract. Structure was explored by extracting the eight factors using varimax (orthogonal) rotation and studying the pattern and magnitude of the loading (degree of association) of each survey item on each factor. The eight extracted factors explained 51.70% of the variance in the data set. The high degree of relatedness of the items within each factor permit the scores of these items to be combined into a single *subscale score*, shown in *Table 1*. The subscale names chosen in this table are indicative of the items that formed the factor.

Table 1 : Identified subscales and corresponding item numbers

Subscale	**Items**	**Instrument Factors**								**Average self-concept**
		M	**A**	**G**	**E**	**Pe**	**Pr**	**C**	**H**	
1. Mathematics / Academic	33, 49, 17, 25, 41, 50, 9, 34, 57, 66, 26, 65, 74, 73, 1	10	5	-	-	-	-	-	-	71%
2. General Self-concept	79, 7, 23, 31, 39, 63, 15, 47, 71, 55, 80	-	-	10	-	-	-	-	1	71%
3. Engineering Affect	60, 76, 36, 52, 4, 67, 35, 22, 54, 3	-	-	-	5	2	3	-	-	73%
4. Peer Interaction	62, 30, 70, 78, 46, 61, 14, 38, 51	-	-	-	-	7	1	1	-	66%
5. Communication Skills	77, 21, 37, 13, 69, 45, 5, 29, 53, 16	-	-	-	-	-	-	9	1	67%
6. Honesty	56, 24, 32, 64, 72, 48, 40	-	-	-	-	-	-	-	8	72%
7. Academic Sentiment	18, 2, 10, 42, 58, 43	-	5	-	-	-	1	-	-	70%
8. Engineering Creativity	68, 44, 27, 28, 20, 11	-	-	-	4	-	2	-	-	71%

Items with loadings of below 0.369 on any factor were not considered to load on it. Five items, with loadings between 0.292 and 0.369 (Q75, Q19, Q12, Q59, Q6) had no strong association with any factor and were not included in the subscale calculations. Three of these were from the original Creativity / Problem Solving scale and interestingly related specifically to creativity, indicating that students did not consider this factor independently in its own right. On the identified subscales, Mathematics / Academic, Engineering Affect and Honesty rated highest, while Communication Skills and Peer Interaction rated lowest on average.

4 DISCUSSION

Several interesting features were revealed when analysing the new subscales generated by the analysis. Of particular interest were subscales 1,3, 7 and 8 as these subscales showed interesting combinations of question groups and/or relationships between them.

Subscale 1 (Mathematics / Academic) comprised all of the mathematics questions plus several academic questions related to students' perceptions of their skill, for example "I learn quickly in most academic subjects". Both the academic and mathematics questions in this subscale were negatively aligned (positive questions have negative components and vice versa) which implies that negative perceptions of academic skill are aligned with negative perceptions of mathematics. This might reveal a relationship between perceived ability in mathematics and academic confidence and suggests benefits in building stronger confidence in mathematics in first-year students.

Subscales 3 (Engineering Affect) and 8 (Engineering Creativity) could be considered similar as they both contain a mix of engineering and problem-solving questions. Subscale 3 appears to measure an apprehension towards engineering indicated by the fact that it contains only negatively phrased questions, e.g. "Engineering Intimidates me" and "I'm not much good at problem solving", which are negatively aligned. Subscale 3 also contains two peer related questions that are also negatively aligned. This suggested the subscale was measuring a form of engineering affect.

Conversely, subscale 8 appears to measure engineering creativity and confidence in ability as indicated by a combination of skills-based problem-solving questions and engineering questions such as "I am quite good at dealing with engineering concepts". These questions are positively worded questions and are positively aligned. Unsurprisingly, both subscales strongly link problem-solving with engineering self-concept and thus improving problem solving confidence in first-year students could be key to reducing engineering apprehension and improving retention. Tracking problem-solving ability could also be a relatively straightforward method of tracking engineering self-concept.

Finally, subscale 7 (Academic Sentiment) appears to measure positive sentiment towards academic ability. The questions in this section are positively aligned and are mostly academic questions with one question relating to problem solving. These questions all relate to a students' sentiment or attitude towards academic subjects, e.g. "I like most academic subjects" or "I hate studying for many academic subjects". It is interesting to note that academic sentiment is separated from perceived academic ability, which is captured along with mathematics in subscale 1. Furthermore, academic sentiment is not aligned with self-concept in engineering, which is contrary to similar work involving engineering Masters students (Buskes 2019) who have likely had time to develop such an alignment. In future, it will be insightful to measure academic sentiment at the end of semester to see if it becomes more aligned with engineering self-concept.

Communication Skills and Peer Interaction had the lowest self-concept, with an average of 66-67%. This is likely due to the first-year cohort not yet having many opportunities to develop skills in these areas (potentially amplified through the effects of COVID-19 at high-school) and emphasises the need for more targeted development of these skills in the first-year cohort.

5 SUMMARY

In order to discover more about students' backgrounds and experiences, approximately 350 first-year engineering students were surveyed to assess their self-concept across eight distinct domains. It was revealed that students had lower self-concept in the factors of Communication Skills, Peer Interactions, and Problem Solving than in Mathematics, Engineering Affect and Honesty. Further analysis found that students strongly associated academic ability with perceived skill in mathematics and identified a pair of composite factors relating to engineering – one that captures affect towards engineering (Engineering Affect) and one that captures students' perceived relationship between engineering and problem solving (Engineering Creativity). The implementation of such a survey has permitted building a more complete picture of student self-concept, the results of which will be used to develop activities and programs to suit students' needs, particularly in terms of improving peer interaction and communication skills.

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