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The effects of gender on the success of a cohort of engineering students

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Abstract: *The gender imbalance in the Australian engineering profession is significant and many engineering educators seek to redress this imbalance. This paper considers the implications of gender on the academic success of male and female students in engineering and spatial science programs.*

In 2004 the authors began a longitudinal study to identify the key predictors of academic success for a sample of 131 (18 females) on-campus students enrolled in first-year engineering and spatial science programs at the University of Southern Queensland (USQ). Earlier papers reported on the individual differences factors that influenced academic success, showing that previous education achievement (tertiary entrance score) was the key factor in predicting academic success for engineering students during their first year of study (Burton and Dowling, 2005; Dowling and Burton, 2005; Burton, Taylor, Dowling and Lawrence 2009). This paper explores the nature of the relationships between cognitive abilities (spatial and verbal skills), personality, and academic success, for male and female students while they were enrolled in their program.

Analysis of the data showed that academic success in first year proved to be a significant predictor of success for the remaining years of the program, and that the personality traits Agreeableness and Emotional Stability contributed to this success. The data also shows that although the attrition rate for the females was more than that for male students, the females were generally successful in first year. Had they continued, they would have successfully completed their engineering program because they had experienced success and had the cognitive abilities and personality traits that predicted success in the longer term.

Introduction

Both the Australian Council of Engineering Deans (ACED) and Engineers Australia, the peak body for the profession in Australia have identified a severe skills shortage as a major issue facing industry and national infrastructure needs (ACED, 2008; Engineers Australia, 2008). The ACED report identified as critical issues the continuing reduction in the size of the pool of Australian school students who are studying the requisite high levels of mathematics and science, and the low participation rate of women in university engineering programs (females currently represent 15% of students in engineering programs (ACED, 2008)). Among the recommendations of this report were:

- the need to increase the public understanding of engineering and the work of engineers, particularly in high schools; and
- the need to attract a higher proportion of women and other under-represented groups to the profession.

Many previous researchers have commented on the reasons for a small proportion of female students in Engineering. Sullivan (2007) found that many girls misconceive engineering as “a man’s profession” and believe it has a lower impact on people’s lives than other scientific fields such as medicine and biology. As a result, girls are not motivated to study engineering even though they complete high school science and maths at the same rate and quality as boys. Similarly, Schreuders, Mannon and Rutherford (2009) found that few females studying engineering lack the abilities or confidence needed for academic success. Rather, they reported that females have little experience in using tools and machinery relevant to engineering studies and educators should provide opportunities in the curriculum for female students to practise and develop their technical skills and confidence.

The results of this study, which focuses on identifying the effects of gender on student success in engineering programs, should help to redress this imbalance by informing future curriculum design activities. It is timely as many Engineering Schools in Australia are experiencing increased diversity in the characteristics of their commencing cohorts. Venter (2003) suggested that teachers must respond to student diversity so they can enable each student to become a confident, self-directed, and independent learner. An inclusive learning environment that caters for the increasing diversity among commencing student cohorts may make the difference between success and failure. The challenge, then, is how to better understand the characteristics of the students in the commencing cohort and, in so doing, provide recommendations for the development of a nurturing educational climate that facilitates the achievement of the prime goals, which are quality learning and academic success for all students.

The key characteristics that were explored in this study are introduced and discussed in the following paragraphs, and then related to the relevant findings from the research literature.

Research evidence indicates that students enter university with expectations about the learning experience, which influences their approach to study (Krause, Hartley, James, & McInnis, 2005). On the other hand, students are often poorly informed about the nature of their coursework (Krause et al.) and inappropriate discipline choice is an important determinant of student withdrawal (Yorke & Longden, 2008).

On the other hand, Vogt, Hocevar and Hagedorn (2007) found that both workload and discrimination strongly influence female students' decisions to continue their engineering studies. Their study found that female students had to put greater effort into studying engineering than males and that the female students reported greater gender discrimination than the male students. While Concannon and Barrow (2009) reported that there is no significant difference in self-efficacy between male and female engineering students, Vogt, et. al (2007) found that self-efficacy has more positive impact on females than males in promoting student effort, help-seeking and critical thinking. Therefore, enhancing females' self-efficacy might be considered in future curriculum design activities.

It is clear that cognitive abilities and spatial abilities play an important role in predicting academic achievement in engineering studies (see Sorby, 2009; Sutton et. al 2009a; Sutton et al, 2009b; and Magin & Churches, 1996). It is also the case that a number of non-cognitive factors, including personality and self-efficacy, help shape an individual's academic performance (O'Connor & Paunonen, 2007). Some of the Big Five personality factors such as Conscientiousness and Agreeableness account for unique variance in achievement after IQ has been taken into account (Farsides & Woodfield, 2003). However, unlike the present study, many studies conducted with university students have not tracked performance over time to see if the key predictors of successful transition into first-year at university also predict success in the program over time.

There is a gender effect in spatial abilities, with males outperforming females (see Sutton, Williams & MchBride, 2009b). Sutton et al. found that the more experience in technical drawing and design students have, the higher their spatial skills. This suggests that spatial skills should be taught in secondary schools, especially for female students who typically have less experience than their male counterparts. However, Sorby (2009) believes all engineering students, not only females, can benefit from specific training in spatial and technical skills – it helps them to build confidence and reduce attrition.

Male, Bush and Murray (2009a; 2009b) reported that females' competence in verbal communication and teamwork are significantly higher than males, and that these two workplace competencies were ranked in the top ten most important competencies of the 64 competencies ranked by the practising engineers who participated in their study.

The present study extends previous work by tracking a sample of first-year on-campus engineering students through to completion of their programs. The aim is to examine the key individual differences (e.g., cognitive abilities and personality traits) and socio-cultural factors (e.g., previous educational experience) that influence the academic achievement of first-year engineering students over time. A key research question was to determine whether personality, cognitive abilities, including verbal and spatial abilities, and prior educational experience each predict grade point average (GPA) both at the end of first-year and again at the completion of their programs. By identifying the key factors that impact on student learning, adjustments to the teaching and learning environments can be made to ensure a smooth transition to university and a successful outcome in their program. In reporting these outcomes, the focus of this paper is on the role that gender plays in relation to the impact of these individual differences.

Methodology

A battery of tests was developed to create a "learning profile" for each student by identifying students' learning preferences, cognitive abilities (e.g., general reasoning, verbal, and spatial abilities), and major personality traits. The battery was developed for use in a longitudinal study of individual differences in student achievement. However, only those measures relevant to this paper are discussed here.

In 2004, the battery was administered via paper-and-pencil, however, from 2006, a refined battery was administered online, providing a more efficient data collection process and enabling distance education students to also participate in the project. The 2006 data is under analysis and will be compared with the findings reported here relating to the 2004 on-campus cohort.

Individual feedback was provided to each participant summarising their learning preferences, cognitive strengths, and weaknesses and outlining strategies for optimising their learning.

Participants

A total of 134 commencing on-campus students (18 females and 116 males) initially participated in the study in 2004. However, valid data was obtained from only 131 of the students and complete data from 66 students. Of the 131 students 18 were females (14%) and 113 males, with a mean age of 20.20 years (*Min* = 17, *Max* = 43, *SD* = 5.17). The mean age for males was 20.53 years (*Min* = 17, *Max* = 43, *SD* = 5.44), and 18.17 years for the females (*Min* = 17, *Max* = 25, *SD* = 2.15) suggesting that most of the females came directly from high school to university.

The students began their studies in Semester 1, 2004, in one of the following types of programs offered by the Faculty of Engineering and Surveying in the engineering or spatial science fields: a two-year Associate Degree; a three-year Technology degree; a four-year professional degree; or a five-year combined degree.

The majority of the students (108) applied for admission to the program through the Queensland Tertiary Admission Centre (QTAC). These students were allocated a Rank (the lowest Rank is 1 and the highest is 99) which was then used by universities to select students for their programs. The remaining 26 commencing students were either international students who applied directly to USQ or existing USQ students who transferred to the program from another program. Most of these students had not previously studied engineering or surveying. Eight had completed a preparatory studies program at the university.

Cognitive ability tests

General reasoning, verbal, and spatial abilities are cognitive abilities often shown to predict academic achievement (Rothstein & Paunonen, 1994). All three cognitive abilities are clearly relevant to success in the engineering profession, especially spatial ability (Strong & Smith, 2002). Each of the following reference tests were from the Ekstrom, French, Harman, and Dermen (1976) kit of factor-referenced cognitive tests, except where otherwise indicated. These tests are recognised as standard measures of cognitive abilities in the field of individual differences. The dependent variable for each reference test was the total number correct. General Reasoning ability (the ability to reason, form concepts, and problem solve with novel information) was measured by the following three tests: (a) Letter Series (20 items; Thurstone & Thurstone, 1965), (b) Number Series (20 items; Thurstone & Thurstone), and (c) Matrices test (10 items; Cattell & Cattell, 1965). Verbal ability (the ability to process information presented as words) was measured by summing performance across three tests: (a) Scrambled Words (25 items), (b) Hidden Words (56 items), and (c) Incomplete Words (18 items).

A total of nine marker tests were included to measure three major spatial factors: Spatial Relations, Visualisation, and Spatial Scanning.

The Spatial Relations factor reflects the ability to perceive an object from different positions. Spatial Relations ability was computed by summing performance on the following tests: (a) Card Rotations (80 items), (b) Cube Comparisons (21 items), and (c) Spatial Relations (70 items; Thurstone & Thurstone, 1965). The Visualisation factor reflects the ability to apprehend a spatial form and rotate it in two or three dimensions before matching it with another spatial form.

Visualisation ability was computed by summing performance on each of the following tests: (a) Paper Form Board (120 items), (b) Paper Folding (10 items), and (c) Surface Development (30 items).

The Spatial Scanning factor reflects the speed with which you can mentally scan a map or object and find a path or connection between two points. Spatial Scanning ability was computed by three mental scanning tests: (a) Maze Tracing Speed (4 items), (b) Choosing a Path (16 items), and (c) Map Planning (20 items).

Personality and general self-efficacy measures

The self-report survey began with a request for demographic information on variables including gender, age, language, nation of origin, field of study, and experience. Additionally, data on student Queensland Tertiary Admission Centre (QTAC) Ranks and High School Year 12 subject results were obtained from student records. Self-report measures of preferred learning styles were also included in the survey.

The short form of the International Personality Item Pool (IPIP, Goldberg, 1999) was used to measure the Big-Five factors of personality: Openness to Experience, Conscientiousness, Extraversion, Agreeableness, and Emotional Stability. Participants completed the 50-item IPIP using a 5-point Likert-type scale (1 = *very inaccurate;* 5 = *very accurate*). Total scores for each major trait could theoretically range between 10 and 50. Goldberg (1999) showed that the five IPIP scales each demonstrated acceptable internal reliabilities, with coefficient alpha estimates ranging between .79 (Conscientiousness) and .87 (Extraversion).

General self-efficacy (GSE) reflects a person's optimistic belief in their ability to cope with a variety of stressful or challenging situations. The revised version of the GSE (Schwarzer & Jerusalem, 2000) consists of 10 items that relate to people's feelings of mastery in a variety of situations. Participants were asked to rate their agreement with each of the statements from 1 (not at all true) to 4 (exactly true). All of the items were positively phrased, with a total Self-efficacy score ranging from 10 to 40.

Academic performance

Academic success was measured using the student's grade point average (GPA), at the end of each semester, although only their first-year GPA (GPA_Y1) and a 2009 GPA (GPA_09) are reported here. In the case of students who have graduated or cancelled from the program, their final GPA was used for GPA_09. A student's GPA is the average of the grades they achieve in the subjects they complete, based on a seven point scale, with 1.5 being awarded for a Fail grade, 4 for a Pass and 7 for a High Distinction.

Procedure

The total testing time was about 2.5 to 3 hours, broken into two, one-hour test sessions and a take-home self-report survey. The first session involved the timed general reasoning and verbal ability tests and the first half of the spatial ability tests. The second session included the second half of the spatial ability tests. A maximum of 25 people were present in each test session as students completed these tests during weekly tutorials. At the end of the second test session, students were given the self-report survey to complete in their own time. They were required to return the completed survey in a sealed envelope within one week. Testing was carried out over a 4-week period. Students who completed the full battery of tests received personal feedback on their learning profiles.

Results

The descriptive statistics for the key variables are shown in Table 1. At the end of 2009, after six years of study, 34 students were still enrolled in their engineering or spatial science program, 38 had graduated, 9 had transferred to a program offered by another Faculty, and 50 had cancelled from their program and departed USQ (including 10 males who were excluded from their program). At the end of the first year, five of the 18 females had transferred to a program offered by another Faculty at USQ, and two of those have since graduated.

Significant gender differences were found for QTAC Rank, $F(1, 108) = 8.51$, $p < .01$, with females (M = 87.15, SD = 8.98) out-performing males (M = 79.841, SD = 11.14). Nevertheless, both male and female students were, on average, successful in their studies both in first year, and in the later years of their program.

Table 1: Descriptive statistics

Variable	Male			Female			Overall Sample		
	N	Mean	SD	N	Mean	SD	N	Mean	SD
Enrolled	33			1			34		
Graduated	32			6			38		
Transferred	4			5			9		
Cancelled	44			6			50		
GPA_Y1 (End of 2004)	110	4.49	1.29	18	4.81	1.05	128	4.52	1.26
GPA_09 (End of 2009)	110	4.14	1.33	18	4.59	1.01	128	4.20	1.30
Verbal ability	98	63.11	16.36	16	73.31	14.53	114	64.54	16.45
Spatial Relations	102	96.38	37.98	16	114.69	31.44	118	98.86	37.57
Visualisation	65	99.28	28.73	14	106.21	27.18	79	100.51	28.42
Spatial Scanning	65	33.02	9.15	14	32.79	8.33	79	32.97	8.96
Openness to experience	53	33.81	5.86	13	36.54	6.02	66	34.35	5.95
Conscientiousness	52	35.46	5.37	13	36.23	5.78	65	35.62	5.42
Extraversion	52	30.52	7.37	13	32.77	9.30	65	30.97	7.77
Agreeableness	48	37.88	5.40	13	39.46	6.54	61	38.21	5.64
Emotional Stability	52	31.58	6.91	13	30.62	6.86	65	31.38	6.86
Self-efficacy	54	37.98	5.38	13	41.15	6.30	67	38.60	5.66

Statistically the females performed significantly better than the males in Verbal ability $F(1, 113) = 5.50$, $p < .05$. No other gender effects were evident, with males and females showing comparable results for General Reasoning ability and all three forms of spatial abilities.

Additionally, the female and male cohorts showed similar personality profiles. Both scored highest, on average, on the personality trait Agreeableness. In contrast, the females scored lowest, on average, on the Extraversion trait and the males scored lowest, on average, on the Emotional Stability trait. However, these differences were not statistically significant. No gender effect was found for self-efficacy, indicating that the female students showed self-confidence scores comparable to their male counterparts.

Correlation and regression analysis

Table 2 shows the relationships between GPA_Y1 and GPA_09 and QTAC Rank, General Reasoning, Verbal ability and spatial abilities (Spatial Relations, Visualisation and Spatial Scanning). The QTAC Rank was significantly correlated with both measures of academic success, sharing approximately 40% of the common variance. QTAC Rank was also significantly correlated with all cognitive ability measures. Extraversion and Spatial Relations were also significantly correlated with both measures while Verbal ability and Agreeableness were significantly correlated with GPA_09.

Hierarchical regression analyses were then performed to determine the unique predictors of academic success, both in first year and at the end of 2009 or their studies.

The initial analysis, as shown in Table 3, using GPA_Y1 as the dependent variable, included QTAC rank, plus General Reasoning ability, Verbal ability, the three spatial abilities and Extraversion and Self-Efficacy as predictor variables. QTAC Rank was entered at step 1 and the result was significant

$F(1,129) = 57.46$, $p < .01$. At step 2, only QTAC Rank ($\beta = .55$, $t = 5.46$, $p < .01$) and Extraversion ($\beta = .17$, $t = 2.32$, $p < .05$) significantly contributed to the model, $F(8,130) = 9.47$, $p < .01$, $R^2 = .38$. Extraversion contributed an additional 8% to the total variance explained.

Table 2: Correlation Matrix

Variables	GPA_Y1	GPA_09
Cognitive Abilities		
General Reasoning	.22*	.18
Verbal ability	.41*	.33**
Spatial Relations	.41**	.27**
Visualisation	.24*	.13
Spatial Scanning	.26*	.22*
Personality Traits		
Openness to Experience	-.02	-.03
Conscientiousness	.20	.30*
Extraversion	.34**	.33**
Agreeableness	.24	.42**
Emotional Stability	.15	.31*
Self-Efficacy	.27*	.28*
Other Indicator Variables		
QTAC Rank	.66**	.63**

*Note: *p < .05. **p < .01.*

The final regression analysis, using GPA_FY as the dependent variable (see Table 4), included GPA_Y1 plus Verbal ability, Spatial Relations, Conscientiousness, Extraversion, Agreeableness, Emotional Stability and Self-Efficacy as predictor variables. GPA_Y1 was entered at step 1 and the result was significant, $F(1,129) = 174.21$, $p < .01$. At step 2, only GPA_Y1 ($\beta = .71$, $t = 11.51$, $p < .01$), Agreeableness ($\beta = .18$, $t = 2.96$, $p < .01$), and Emotional Stability ($\beta = .15$, $t = 2.50$, $p < .01$) significantly contributed to the model, $F(8,130) = 27.30$, $p < .01$, $R^2 = .64$. Together, the two personality variables contributed an additional 7% to the total variance explained.

Implications and future research directions

Cognitive abilities

Consistent with previous research (Strong & Smith, 2002), spatial, in particular Spatial Relations skills that enable individuals to mentally manipulate and rotate objects, correlated significantly with academic success in engineering programs. Thus, students deficient in these skills should be given the earliest opportunity to acquire those spatial skills that facilitate academic success.

Verbal abilities are also relevant to academic success and if, as Male et.al (2009a; 2009b) reported, the competence of female students in verbal communication skills is significantly higher than males, then female students should perform better than their male counterparts in the relevant engineering subjects.

Personality

The students in the sample scored highest on the Agreeableness personality trait, although extroverted students were more likely to be successful in first-year. In final year, Agreeableness and Emotional stability added to the prediction of academic achievement beyond that provided by success in first year studies. This finding is consistent with previous research that found Introverted and Agreeable students were more likely to be successful in their studies (McKenzie et al., 2004).

Table 3: Regression Analysis (GPA_Y1)

Dependent Variable	Independent Variables	β	*SE B*	*t*
GPA_Y1 – Step 1	QTAC Rank	.55	.01	7.58**
GPA_Y1 – Step 2	QTAC Rank	.47	.01	5.46**
	General Reasoning	-.06	.01	-0.63
	Verbal ability	.14	.01	1.52
	Spatial Relations	.14	.01	1.54
	Visualisation	.08	.00	0.97
	Spatial Scanning	-.11	.02	-1.12
	Extraversion	.17	.02	2.32*
	Self-efficacy	.02	.02	0.32
Step 1	R^2 = .30			
	Adjusted R^2 = .30			
Step 2	R^2 = .38			
	Adjusted R^2 = .34			

Note: **p < .01; * p < .05.

Table 4: Regression Analysis (GPA_09)

Dependent Variable	Independent Variables	β	*SE B*	*t*
GPA_09 – Step 1	GPA_Y1	.76	.07	13.20**
GPA_09 – Step 2	GPA_Y1	.71	.08	11.50**
	Verbal ability	.02	.01	0.35
	Spatial Relations	-.04	.00	-.67
	Conscientiousness	.04	.02	.59
	Extraversion	.02	.02	.27
	Agreeableness	.18	.02	2.96*
	Emotional Stability	.15	.02	2.50*
	Self-efficacy	.00	.02	.00
Step 1	R^2 = .57			
	Adjusted R^2 = .57			
Step 2	R^2 = .64			
	Adjusted R^2 = .62			

Note: **p < .01, * p < .05.

The results also showed that females and males have similar personality profiles. This finding may reflect changes in the curriculum brought about by an increasing emphasis, by both the University and Engineers Australia (the accrediting institution), on the teaching and assessment of generic attributes and capabilities, such as communication skills and teamwork. For example, a number of the core

problem solving courses involve a substantial amount of team work and a considerable component of the assessment is based on communication skills and team processes and outcomes. Emotional stability also added to the prediction, showing that resilience and ability to deal with stress facilitates academic success in the long-term.

Additionally, the students must report verbally on the results of their work in a number of courses. It is therefore understandable that extroverted and/or agreeable students, who feel confident and comfortable consulting and collaborating with others, socialising, and working in teams, are more likely to be successful in assessments measuring these capabilities than their less social peers.

One implication is that the problem based learning curriculum may be rewarding extroverted and/or agreeable students in their assessment practices, particularly in first year. Extroverts are expected to succeed in a relaxed, group learning environment in contrast to introverts who are more likely to be attracted to a highly organised and independent learning environment (Eysenck, 1996). If the current findings are replicated in the distance student datasets, then the Faculty should consider strategies to engage the more introverted students in learning, especially during their first year of studies. This will provide such students with more time to become familiar with the learning and teaching environment and facilitate a smoother transition to the university. Emotional stability also added to the prediction, showing that resilience and ability to deal with stress facilitates academic success in the long-term.

This study identified, but did not resolve, a key question for the Faculty: Why did some of the female students leave their program despite having experienced success and having the cognitive abilities and personality traits that predicted success in the longer term?

Conclusion

The aim of this study was to determine the relative impact of previous educational achievement, cognitive abilities, personality variables, and gender on academic achievement in undergraduate engineering programs. The results of the analyses are quite clear: both previous academic achievements, verbal and spatial abilities, and personality predict academic success. The current results provide further support for the claim that personality is important in the higher educational sector. The regression analysis with personality variables showed that Extraversion trait was the only personality variable to predict academic performance in first year. It seems less relevant over time, however, as other traits became more relevant to the prediction of academic success over the longer term. For example, Agreeableness and Emotional Stability become important in later years of the program, perhaps reflecting the problem based learning curriculum and its emphasis on team work. These findings offer general support for the importance of personality in predicting academic success even when previous educational experience and cognitive ability are controlled.

The findings relating to the impact of gender on academic success in the engineering programs are mixed and should be treated with caution due to the small sample size. The large attrition rate for the female students, particularly in first year, should be compared with that of other years to see if it is replicated for those cohorts. On the other hand, the study found that the female students who persisted were likely to be more successful than their male counterparts, and that this may be due to their personality and enhanced verbal skills.

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