Can we select students who will go on to be successful engineers?

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STRUCTURED ABSTRACT

CONTEXT
Tertiary entrance scores are widely used for admissions into engineering degrees, and these scores have been shown to correlate with academic performance. However, academic performance is not always well correlated with work performance. This suggests that the exclusive use of tertiary entrance scores for university admissions may not select students who can develop into high-performing engineers. In contrast, some psychometric measures, such as conscientiousness and general mental ability (GMA), are correlated with both tertiary and work performance, but the validity of these measures can be affected by demographic factors, including culture (e.g. nationality, race, or ethnicity), gender and age.

PURPOSE
This study will explore the affordances of including different selection methods into the admission process for an undergraduate engineering degree.

APPROACH
This study reviewed literature to explore the relationships between different selection methods, academic and work performance. The applicability of some of these selection methods in admissions processes will be examined and discussed.

RESULTS
General mental ability is a key predictor of work performance, and other non-cognitive scores can improve this prediction. Grade point average (GPA) is a poor predictor of work performance. Multiple-mini interviews, currently used in medicine, have strong potential as an alternative selection method.

CONCLUSIONS
Existing selection methods have the potential to be adapted and used to select a diverse engineering cohort. Alternative academic performance metrics are urgently needed to predict work performance.

KEYWORDS
Admission; psychometrics; academic performance; work performance

Introduction

The Engineering Practice Academy at Swinburne University of Technology has a strong focus on admission of students with a strong potential for work performance. Academic success is most typically operationalised by a measure of academic performance, typically a grade point average (GPA) (Trapmann, Hell, Hirn, & Schuler, 2007). GPA is an objective measure, with demonstrated internal (i.e., institutional) reliability and temporal consistency, although there are issues related to institutional grading differences and grade inflation (Richardson, Abraham, & Bond, 2012). However, academic success has also been shown to relate to characteristics, including self-confidence, self-efficacy, satisfaction and retention (Trapmann et al., 2007; Vogt, Hocevar, & Hagedorn, 2007).

In Australia, most engineering programs require a minimum ranking for entry, based on the Australian Tertiary Admission Rank (ATAR) system, and is used as the primary pathway for most domestic students matriculating from high-school. The very premise of university selection is based on a student's ability to perform in a tertiary education environment (as measured by GPA), rather than the workplace. Indeed, one paper states that "University admissions … should predict an applicant's ability to succeed in college" (Stemler, 2012, p. 5). In contrast to academic performance, work performance can be defined as performance in practice (Lievens & Sackett, 2012), and is typically characterised by either an intrinsic measure of success or satisfaction, or extrinsic measures related to income and promotion (Judge, Higgins, Thoresen, & Barrick, 1999; Wille, De Fruyt, & Feys, 2013). However, there is no published research or clear evidence to support that ATAR will predict performance in a workplace after graduation from university. It has been suggested that the ATAR system is not always a good predictor of success, and can understate potential (Harvey, Norton, Matters, & Pitman, 2016). This may be because ATAR can be a predictor of GPA (Messinis & Sheehan, 2015), but GPA is not always a strong predictor of work performance. GPA can be important shortly after graduation, but its ability to predict work performance diminishes as graduates become more experienced or qualified (Roth, BeVier, Switzer, & Schippmann, 1996).

Other aspects of the ATAR system have been subject to criticism. Australia's Chief Scientist, Alan Finkel, recently suggested that the ATAR system demotivates students from taking STEM subjects in high-school (Koziol, 2018) due to an 'absorbed message' that the way to boost ATAR is to choose high-school subjects that are less challenging (Education Council, 2018). In addition, there is a positive correlation between ATAR and socio-economic status (SES; Lamb, Jackson, Walstab, & Huo, 2015). However, when SES is accounted for, students in the same ATAR band are equally likely to attend university (Palmer, Bexley, & James, 2011), and are equally as likely to perform well when at university (Li & Dockery, 2014; Palmer et al., 2011). This indicates that students perform equally well when SES is controlled for, regardless of their SES demographic beforehand, provided they are accepted into university. In this respect, selection based solely on ATAR from secondary school will work against efforts to promote some types of diversity [i.e. factors where SES has influence (Palmer et al., 2011)]. Despite these criticisms, ATAR remains a good predictor of university retention and completion rates (Norton, Norton, & Cakitaki, 2016).

The use of alternative selection methods for engineering students is limited. This is despite research showing that personality traits, motivational factors, self-regulated learning strategies, learning and psychosocial factors have also been shown to contribute to academic and work performance (Richardson et al., 2012). In contrast, medical and health disciplines have relied on a range of student selection techniques (at the undergraduate and graduate entry levels), beyond prior academic achievement, for the last 50 years, including aptitude tests, personal statements, personality assessments, references, emotional intelligence assessments, situational judgment tests and selection centres (Patterson et al., 2016; Pau et al., 2013). These additional measures are premised on increased expectations of medical and health practitioners to not only be technically competent, but for these professionals to have, or have the potential to develop, attributes needed for clinical practice (Patterson et al., 2016). Indeed, many of the methods used for the selection of students in health disciplines are commonplace for employment selection (Schmidt, Oh, & Shaffer, 2016). In summary, these selection methods are intended to not only select students who will achieve academic success, but those who will go on to meet the performance expectations of their workplace.

These sentiments of the changing needs of health professional attributes are paralleled with those in engineering. It is forecast that in the next 20 years, the rise of automation will likely result in engineers spending less time undertaking routine technical tasks (Frey & Osborne, 2017), and more time engaging with people (Foundation for Young Australians & AlphaBeta, 2017). Engineers of the future will need to be adaptable, flexible, resilient and creative to manage the challenges associated with

globalisation (Australian Workforce and Productivity Agency, 2014). This will bring higher expectations of human-centric attributes, in addition to technical understanding, similar to those required of medical and health professionals. Finding the engineers of the future will require selection methods for engineering students that are reliable, valid and based on sound evidence, and encompass aspects of work performance.

This paper reviews and discusses literature in relation to the following research question: *What selection methods could be used to identify an engineering student's potential for success, not only at university, but also in life after university, whilst at the same time being practical, and supporting broader inclusion?* It then discusses the opportunities, and practical measures associated with implementation of some of these alternative methods in practice, with consideration of gender, culture and age..

Methodology

The alternative methods used in selection of students largely draw from established methods in employee recruitment. These methods are extensive, and it is not the intent of this paper to review each of these. Of the different methods, general mental ability (GMA, also reported as general intelligence or general cognitive ability, or the *g* factor) has been shown to consistently predict a broad range of life-outcomes, including academic performance, work performance and creativity (Schmidt et al., 2016). GMA can be operationalised by a range of instruments, including the Miller Analogies Test. Other methods have been consistently shown to compound with GMA for work performance, and these form the basis of this review. The alternative methods reviewed in this paper were limited to those reported in Schmidt et al. (2016). Methods that had a gain in validity (over GMA alone) of less than 5% were excluded, as were those methods that would be immediately unsuitable as a student selection measure. Specifically, biographical data were excluded based on privacy; it is unlikely that selection of students would allow for disclosure of life experiences, including professions of parents. Years of experience and vocational interest were also excluded, on the basis that most applications into engineering have limited work experience within engineering. Grade Point Average (GPA) was included on the basis as being the primary measure of academic performance. This paper therefore is limited to the following selection methods:

- General Mental Ability (GMA)
- Integrity tests
- Interviews (structured or unstructured)
- Conscientiousness
- Openness to experience
- Reference checks
- Emotional intelligence (EI)
- High-school scores and university entrance scores
- Grade Point Average (GPA)

The excluded selection methods were:

- Person-organisation fit
- Person-job fit
- Situational judgment tests
- Extraversion
- Emotional Stability (and conversely, neuroticism)
- Peer ratings

A "state-of-the-art review", as described by (Grant & Booth, 2009), was used to identify how these methods relate to academic and work performance, with the aim of providing a new perspective and potential areas for future research. The review excluded literature associated with matters associated with student attrition, attendance and retention. Boolean key search terms included: engineer*, selection, performance, job, work, academic, university, tertiary, recruit*, ability, training, undergraduate, graduate, admission, admit, choose, employee, methods, technique, procedures, success, ATAR, integrity tests, interview*, conscientiousness, referee, reference checks, openness to experience, emotional intelligence. The wildcard operator (*) was used to capture truncated terms.

Description of identified selection methods

Integrity tests aim to predict dishonesty at work, and are typically operationalised by a number of instruments. For example, the Personnel Selection Inventory and Reid Report (Ones & Viswesvaran, 2001), and are of varying length and format.

Interviews can either be structured or unstructured. Structured interviews are typically designed to match questions with specific attributes and skills required for the position, whereas unstructured interviews typically have no set format or list of questions.

Personality traits are most commonly characterised by the five-factor model (often referred to as the OCEAN model, or the big five model), and is typically operationalised by the NEO Personality Inventory – Revised (NEO-PI-R, (Costa, 1992)), most typically involving self-reporting on a Likert scale against a range of statements. The five-factor model assesses different personality traits including openness to experience, conscientiousness, extroversion, agreeableness, and neuroticism. The NEO-PI-R disaggregates these traits into thirty facets. More recently, grit, characterised by perseverance and passion (Duckworth, Peterson, Matthews, & Kelly, 2007) has been identified as a potential personality trait that could be used for selection. Despite its recent popularity, there is little evidence to suggest that grit is a strong predictor of work performance (Credé, Tynan, & Harms, 2017).

Reference checks can be written (in the form of recommendation letters) or verbal responses, and often include questions relating to ability, social skills, and past performance (Schmidt & Hunter, 1998).

Emotional intelligence (EI) typically refers to one of two models. The first model describes EI as a set of constructs relating to recognition and control of personal emotion. In the second model, this construct is combined with a set of social skill measurements (Joseph & Newman, 2010). There is some argument to suggest that elements of EI are reflected in measures of conscientiousness, GMA and neuroticism (Joseph & Newman, 2010). EI measures are typically operationalised by either ability-based reasoning tests (like IQ tests), or self-reported using a Likert-scale response to statements.

Predictors of academic success

In this section, the selection methods are discussed in relation to academic success, as measured by GPA. The applicability of the different measures is discussed in relation to diversity.

General Mental Ability is consistently correlated with academic performance (as measured by GPA corrected $r = 0.56$) (Poropat, 2009; Strenze, 2007). The validity of GMA is widely reported as being good. However, Haucknecht et al. (2007) reported that those who resit GMA tests are more likely to do better than those who do not. With respect to diversity, there are reported differences in GMA according to sex (as reported by the Scholastic Assessment Test); males were shown to have different g than females in the 17-18 age group (Jackson & Rushton, 2006). However, differences in GMA measures across sexes can vary, depending on the instrument being used (Griffin & Hu, 2015). Similarly, some GMA measures have been shown to vary depending on cultural background (Song et al., 2010), but there are GMA instruments that do not require previous knowledge or a specific cultural background (Eysenck, 2012). However, even some 'culture-fair' GMA tests have shown to produce different results across cultural groups (Jensen, 1998). Finally, age is an important consideration for the potential use of GMA as a tool for selection, given the typical age ranges of applicants, as GMA generally increases during childhood and adolescence (Rushton & Ankney, 2009).

The intent of ***integrity tests*** is analogous to academic integrity (Lawson, 2004). It has been reported that those who cheat are likely to have a lower GPA than non-cheaters (Kisamore, Stone, & Jawahar, 2007). The applicability of integrity tests, however, is debated, with faking of integrity tests being cited as a concern (Karren & Zacharias, 2007). Despite this, integrity tests have been found to be operationally valid (i.e. limited differentiation) with respect to gender, age and cultural background (Ones & Viswesvaran, 1998).

The use of ***interviews*** for undergraduate selection is limited and is most widely used in admission to graduate schools, particularly in health disciplines. The validity of interviews for student selection are contentious and remain a matter of debate. A number of studies have found no differences in academic performance and attrition for students selected either at random, on prior GPA, or interview ratings (Salvatori, 2001). The internal reliability (e.g., inter-rater scores) of interviews is also highly variable, but the validity and reliability of interviews can be improved by using structured interviews

(Salvatori, 2001). One approach to a structured interview is the multiple mini interview (MMI), used in the selection of health professionals. In the MMI, applicants rotate between different stations intended to reflect non-cognitive attributes expected of the health discipline, including critical thinking, communication and social/ethical situations. At each station, applicants may complete a task, undertake a role-play, or be asked to respond to written statements. Interestingly, it has been shown that the MMI cannot be coached, and scores are reported to be free from gender, cultural (e.g. nationality, race, or ethnicity) and socio-economic status (SES) bias (Griffin, Harding, Wilson, & Yeomans, 2008; Pau et al., 2013). The MMI structure has also found to be effective for the selection of undergraduate students in the United Kingdom (O'Brien, Harvey, Shannon, Lewis, & Valencia, 2011).

Of the ***personality traits*** considered (conscientiousness and openness to experience), conscientiousness has been consistently shown to be a strong predictor of academic performance (Poropat, 2009; Vedel, 2014). Indeed, it has been shown that when added to high-school academic performance, conscientiousness was as good a predictor of academic performance as GMA (Conard, 2006; Noftle & Robins, 2007; Poropat, 2009).

The validity of ***reference checks*** in student selection is questionable, and has similar issues with respect to inter-rater reliability and validity as interviews (Wilson, Roberts, Flynn, & Griffin, 2012). Coupled with this is a potentially high likelihood of bias and faking (Cleland, Dowell, McLachlan, Nicholson, & Patterson, 2012; Wilson et al., 2012); it is unlikely that an applicant would submit a written reference that was not favourable.

It has been shown that there is a modest relationship between ***emotional intelligence*** and academic performance (Perera & DiGiacomo, 2013). The number of studies which investigate variations in EI measures with culture (including race, ethnicity, and nationality) is limited (Joseph & Newman, 2010), and meta-analysis have shown that there can be substantial variations in EI score for different age, race-, and sex-based sub-groups, depending on the instrument used and the specific type of EI construct being considered (Joseph & Newman, 2010; Perera & DiGiacomo, 2013). It has been suggested that EI measures may be better at predicting academic performance in different achievement settings, such as clinical practice in medicine (Perera & DiGiacomo, 2013).

Entrance scores and ***high-school ranking*** are significant predictors of GPA (French, Immekus, & Oakes, 2005). There is some literature to suggest that high-school scores alone are no better a predictor of academic performance than GMA (Strenze, 2007), and that the inclusion of psychometric measures with entrance scores can be better at predicting performance than entrance scores alone (Ting & Man, 2001). In the Australian context, as previously reported, there is evidence to indicate that the ATAR system is skewed against those of SES (Wilson et al., 2012). With respect to sex, it has been shown that females perform better than males across multiple disciplines (including languages, social sciences and mathematics) at different academic level, including high-school, but the effect sizes were small (Voyer & Voyer, 2014). This advantage is a complex issue, and the factors and causes for this are not well understood (Voyer & Voyer, 2014).

Predictors of work performance in engineering

A question arising out of the initial review of the literature was *Are the predictors of work performance in engineering different to any other occupation?* The literature on the traits of engineers, compared to other work disciplines is limited.

For hiring of employees without previous experience, the most valid predictor for future performance is ***GMA*** (Schmidt et al., 2016). In the European Union, for engineering, GMA was found to have a high operational validity as a predictor of training success (Salgado et al., 2003). Training success is a broad term relating to the ability to retain information provided in formal or informal training at work, and is considered a precursor to work performance (David A. Dye & Reck, 1989). In this same study, Salgado et al. (2003) suggest that GMA is more correlated with job complexity, than a specific occupation. Job complexity can be defined as one that is mentally demanding with challenging projects (Ohme & Zacher, 2015). With respect to the other predictors of work performance considered in this study, Barrick and Mount's (1991) meta-analysis of the big five personality traits grouped engineers with other professionals, including architects, lawyers, accountants, teachers and doctors. The correlation scores for conscientiousness and openness to experience for this professional group were close to other occupations, including for police, sales, and skilled/semi-skilled occupations. The limited published literature, reviewed in this paper, suggests that predictors of work performance for engineers are similar to those of other occupations.

Integrity tests were initially developed to predict dishonest behaviours (e.g., theft at work), and have been found to be effective in predicting work performance (Ones & Viswesvaran, 2001). Integrity tests yield an incremental increase in the validity of GMA in predicting work performance (Schmidt et al., 2016). There is a likely overlap between integrity and facets of personality, such as agreeableness and emotional stability, as well as honesty and humility (Schmidt et al., 2016). As previously reported, integrity tests are available which minimise bias.

Structured or unstructured employment ***interviews*** are shown to have a strong operational validity and add to the validity of GMA in the prediction of work performance (Schmidt et al., 2016). As previously highlighted, the validity of interviews is sometimes challenged. However, the MMI has been shown to be a better predictor of personal characteristics in clinical performance than traditional selection methods, such as interviews (Eva, Reiter, Rosenfeld, & Norman, 2004).

Conscientiousness has been consistently shown to be a predictor of work performance, regardless of the occupation (Barrick & Mount, 1991; Dudley, Orvis, Lebiecki, & Cortina, 2006). Conscientiousness can add to the work performance predictive ability of GMA (Schmidt et al., 2016). Dudley et al. (2006) reconfirmed the importance of conscientiousness in predicting work performance, and suggested that narrower traits of conscientiousness (e.g., diligence) could be beneficial in predicting work performance for specific job types, although engineering or related occupations were not considered specifically. Conscientiousness can be important for retention of engineers, and for both individual and team performance (Beard, 2015). Beard (2015) also reported that openness to experience is also a contributing factor for an engineer's performance in a team environment. Personality traits, including conscientiousness, can change over time, including for young adults (Eisenberg, Duckworth, Spinrad, & Valiente, 2014; Trapmann et al., 2007). Personality scores can vary between geographical locations (Allik & McCrae, 2004). Differences in personality traits across gender are modest and these differences have been found to be consistent across different cultures (Costa, Terracciano, & McCrae, 2001).

Reference checks add to the incremental validity of GMA on predicting work performance (Schmidt et al., 2016). Interestingly, much of the data regarding the validity of reference checks are from the United States, and changes in the legal climate and culture have meant that there are gaps in the literature regarding the relationship between reference checks and job performance, meaning that the validity of reference checks in predicting work performance is not resolved (Schmidt et al., 2016). Bias in reference checks also remains an issue (Cleland et al., 2012).

Emotional intelligence (EI) has been shown to be a predictor of work performance, although the strength of correlation depends on the specific model being considered (O'Boyle, Humphrey, Pollack, Hawver, & Story, 2011), and the theoretical basis for EI is underdeveloped (Joseph & Newman, 2010).

The literature investigating the relationship between ***high-school scores*** and work performance is limited. Roth (1996) reported a corrected correlation of 0.19 between high-school grades and work performance, but this can vary depending on the level of schooling (David A Dye & Reck, 1988). The limitations regarding the ATAR system with respect to diversity have been discussed in the Introduction.

Grade Point Average (GPA) is correlated to work performance but as reported previously, this predictive ability diminishes as graduates become more experienced (Roth et al., 1996). Whilst GPA has some predictive ability in itself, it does not necessarily add more prediction than GMA alone (Schmidt et al., 2016).

Discussion

GMA is a promising measure for selecting students, but the practicalities of implementation of such a test would be challenging, particularly given the resources required, and the time commitment needed of applicants (typically 15 to 60 minutes). In contrast, conscientiousness, openness to experience, and Integrity tests are shorter in length than GMA, and could be readily incorporated into a selection system. Reference checks, although having some predictive power in predicting performance, have risks associated with bias and faking. Administering additional measures could be viewed as a potential barrier to admission, which may counter its intent. Nevertheless, the predictive power of some of these measures, particularly, GMA cannot be ignored. Test scores can be adjusted for diversity, but the application of corrections would be difficult, as some diversity data (e.g. SES) is not readily captured by tertiary admission systems. The ethical, legal and regulatory aspects of score adjustments would need to be investigated.

Emotional Intelligence is a new field, and the literature reviewed in this paper suggests that the implementation of EI in selection should be limited until its theoretical underpinnings are better understood.

Interviews are time-consuming, costly to implement and produce data which are less reliable than other selection methods. However, the multiple-mini interview stands out as an interview measure with limited bias, with the ability to predict both academic and work performance, as well as being relatively easy to administer. In this respect, there is an opportunity to adapt the multiple-mini interview technique for selection of engineering students.

The continued use of GPA in university could be a reflection of a shared belief between academia and industry that GPA is important (Aasheim, Shropshire, Li, & Kadlec, 2012), The motivation for the continued use of GPA is not well understood, despite it being proven to be a largely ineffective measure of later work performance.

In contrast, there are continued calls for engineers to have demonstrable attributes beyond GPA. In this respect, an opportunity exists to develop measures that better reflects an engineering graduate's propensity for success in the future, beyond GPA. Recent examples of such measures include (micro-) credential and badging systems at Swinburne University of Technology's Engineering Practice Academy (Cook, 2018) and Colorado State University (DeSilets, 2013). A change in performance measurement at university would be a significant culture shift affecting academics, teachers, high-schools, students, parents, and industry. A change to a new measurement system would likely require a period of transition, including detailed research into its validity, applicability and effectiveness. Despite the difficulties, a change would be beneficial in identifying an engineer's potential for performance in a work environment. Finally, the use of alternative selection methods (e.g. personality traits) has the potential to be used for student guidance, support and development (Hall et al., 2015; Kyllonen, Lipnevich, Burrus, & Roberts, 2014). For example, students with low conscientiousness scores could benefit from supporting interventions.

Conclusions

This paper has identified a need to reconsider the way in which engineering students are selected. Universities can no longer justify measurements of academic performance over workplace performance. A range of alternative methods for selecting engineering students, accounting for work performance potential, bias and practicalities were reviewed. Of all the methods reviewed, the multiple-mini interview, used for selection of students in health disciplines, has the potential to be adapted for selecting engineering students. The development of multiple-mini interview was premised on the need for health professionals to be not only technically competent, but to have strong professional skills, which is now being echoed in the engineering industry. Engineering is undergoing a paradigm shift, which requires bold thinking in the way in which we select students who will go on to work as engineers in the future.

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