Measurement of Characteristics of Engineering Students: What Has Been Done and What Needs to Be Done?

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Abstract
Students' characteristics not only determine their decision making in choosing college major, but also play a significant role in influencing their educational outcomes. Therefore, study of students' characteristics has been one of the important topics in educational research across different subject disciplines. In the area of engineering education, a considerable amount of research effort has been spent on the measurement of the characteristics of engineering students. The measurement results have been applied to predict or explain students' success or failure in engineering education. Characteristics contributing to better engineering education outcomes have been identified. However, different researchers have examined different characteristics of engineering students within the scopes of their own research interests, no universally agreed upon definition of engineering students' characteristics exists in the current literature. In this paper, a comprehensive review and analysis of the existing research on the measurement of the characteristics of engineering students is presented. Specifically, attention has been given in addressing the following questions: 1). what characteristics of engineering students have been measured? 2). what research questions regarding the impact of students' characteristics on their educational outcome have been answered? 3). what measurement and analysis methods have been applied? The author has also pointed out what is lacking in the current research and suggested potential future research directions in this area.

1. Introduction

The fact that engineering education in America is facing critical challenges has frequently been brought up in government reports, academic research results and media. According to a recent report by National Science Foundation (NSF, 2004), the US market demand for engineering graduates has been on the rise for decades, however, the number of students enrolling in engineering majors has been declining during the same time. Furthermore, across all engineering schools, only less than half of the students entering colleges as engineering majors actually graduate with an engineering degree (Astin & Astin, 1992; Besterfielf-Scare, et. al., 1997; French, et. al., 2005). As the number of engineering graduates declines, recruiting and retaining employees with the necessary engineering skills has become one of the most pressing challenges to many mechanical and electrical engineering companies in America (KPMG Report, 2006). In order to attract, retain and train more qualified engineering graduates for the industry, there emerges an urgent call for the reform of engineering education.

As proposed by the National Academic Press report (NAP, 1995), the reform of engineering education demands actions in various sectors including self-assessment and self-evaluation of educational outcomes, balancing faculty incentive systems, improving teaching methods and practices, reforming of curriculum and expanding beneficial interactions and outreaches. Successful college engineering education also relies on the good introductory engineering education in elementary, middle, and high schools to prepare students for the rigors of studying engineering in college (Iversen, et. al., 2007). It is our goal that changes made in these educational sectors will eventually lead to shape our engineering students with the desired characteristics. Students with characteristics prone to engineering are likely to choose engineering as their college major, tend to have higher success rate in completing their education and stay in engineering after they graduate.

This paper aims to present a comprehensive review and analysis of the existing research on the measurement of the characteristics of engineering students. Since students from science, technology and mathematics share many common characteristics as engineering students, the focus of the discussion is centered around but not limited to the framework of engineering education. The representative research studying the common students' characteristics from the fields of science, technology, engineering and mathematics (STEM) have also been included in the discussion. The coverage of this survey spans across the major academic journals, research books and conference proceedings in the areas of engineering education and higher education for the past 20 years.

The rest of the paper is organized as follows. The first part of the discussion summarizes the measurement studies that have been conducted in the current literature. The summaries are presented in these sub-areas: characteristics of engineering students measured, research questions regarding the impact of characteristics on educational outcome answered, measurement and analysis methods applied. The second part of the discussion analyzes the limitation of the current studies, followed by the suggestions for potential future research directions in this area. Finally, the paper concludes this review study by emphasizing the importance of studying students' characteristics. Implication of these research studies in process of reform of engineering education is also discussed.

2. What Has Been Done in The Measurement of Characteristics of Engineering Students?

The strong positive relationships between students' characteristics and their educational performance have long been proven (Fleming & Malone, 1983; Bean, 1986; Tinto, 1987). Within the engineering educational research community, the emphasis has been placed on identifying characteristics that have significant influence on the outcome of engineering education in the contexts of enrollment and retention/attrition. In the past two decades, a considerable amount of research effort has been spent on this topic. However, there exists no universally agreed upon definition of engineering students' characteristics in the current literature. Different researchers have examined different characteristics of engineering students within the interests or limitation of their own research scopes. For example, Tinto (1987) proposed four clusters of characteristics leading to college attrition, namely, adjustment, difficulty, incongruence and isolation. Bean (1986) suggested six clusters of characteristics affecting college attrition which include background, academic integration, social integration, environmental pull, attitudes and GPA. Moller-Wong and Eide (1997) classified characteristics affecting attrition in engineering school into five categories: background, organization, academic and social integration, attitude and motivation, and institutional fit. After examining all these proposed characteristics, the author believes that there have emerged three broad characteristic categories.

2.1. What Characteristics of Engineering Students Have Been Measured?

The first category includes characteristics that are shaped by external factors. Example external characteristics in this category are institutional environment, curriculum requirement, peer or adult influences, average income of engineers, etc. The common feature of these characteristics is that they are the engineering related properties of the community where a student is situated. An individual student is not able to change these characteristics through personal endeavor. Instead, these characteristics will externally yet directly motivate or discourage a student's decision in choosing engineering major and career.

The second category measures engineering students' characteristics that are determined by their internal or personal factors. Only internal characteristics that have direct impact on educational process are relevant to this study. It is well accepted that education is an aggregate of both intellective (cognitive) and non-intellective (affective) processes. Therefore, these internal characteristics are further classified into two sub-categories: cognitive characteristics and affective characteristics. Cognitive characteristics, such as high school math scores, learning style, writing skills, will directly affect a student's academic standing in engineering. Affective characteristics, such as motivation to success, impression of engineering, self-confidence in engineering knowledge or skills, will directly influence students' attitudes towards engineering education. Engineering students bring with them certain academic ability and affective attribution towards engineering and learning when they enter into college. Evolution of the characteristics in these two categories during their stay in engineering school will eventually determine their success or failure in attaining an engineering degree.

The third category measures the demographic characteristics of students. The commonly used variables in this category include age, gender, race, location of residence, socioeconomic status, marriage status, etc. Some of these demographic characteristics actually can fit into either of the two characteristic categories defined above. For example, if a student is from a city where engineers have above average income, "location" becomes an external, environmental characteristic that attracts the student to engineering. For another example, if a student is from an ethnic background where engineering is deemed to be a respectable career, "race" is thus a characteristic that has helped the student to cultivate positive attitude towards engineering. However, since in most survey designs, it is a convention that all these characteristics are measured under demographic category. This convention is retained in this study.

2.2. What Research Questions Have Been Answered?

2.2.1. How do the external characteristics affect the outcome of engineering education?

The external characteristics that have been studied frequently in the literature appear to be peer influence adult influence, curriculum requirement and college environment. Their impacts on engineering education are discussed respectively as follows.

Peer influence. Peer influence is found to be the clearest and most consistent external effect on student's major and career choice. A student faces major peer influence in high school and university. The higher the proportion of a high school student's peers majoring in engineering, the more likely this student will end up choosing engineering (Astin & Astin, 1992; Shuman, et. al., 1999). High school peers' influence is also found to be a good predictor for successfully graduating with a STEM degree (Leslie, et. al., 1998). Friend's encouragement plays an important role not only in a student's college enrollment decision, but also in the retention decision (Bean, 1983). After entering into university, positive peer influence leads to successful education outcome comes from opportunities like participating in honors program, tutoring other students, living on campus (Leslie, et. al., 1998). On the contrary, lack of student community on campus is found to have negative impact on students' retention (Buyer & Connolly, 2006).

Adult influence. Influence from adults around a student is found to be very important in the student's major and career choice (Astin & Astin, 1992; Shuman, et. al., 1999). Family approval exerts both direct and indirect effects in a student's institutional choice and dropout decision (Bean, 1983). In particular, having a father who is an engineer greatly increases a student's chance of choosing engineering major (Astin & Astin, 1992). Having recognized the importance of family influence, however, opinions of the college educators seem to be less influential than they should. As Shuman et. al. (1999) pointed out, very few students who left engineering actually sought out career counseling services provided by universities. Engineering schools should encourage students who consider dropping out or transferring to actively seek help from these services.

Curriculum requirement. Existing research studies have pointed out that most current engineering curricular are overloaded, difficult and lack of relevance to engineering practice. This is arguably one of the most significant external characteristics responsible for the high attrition rate in engineering school. Overloaded content of the current engineering curricular brings too much stress on engineering students (Heywood, 2005). Under the stress of passing many difficult exams, many engineering students have to take an instrumental and mechanical approach to study. Gradually they may lose their interest in learning (Ohland, et. al., 2004). Mathematics is found to be the largest stumbling block causing dropout in the freshman year in engineering schools. Ohland, et. al. (2004) have showed that by relaxing the mathematics pre-requisite, there is an immediate positive effect in grades in the subsequent semester. Currently, most first year engineering curricular cover several pure math and science courses. Many freshman engineering students are thus led to perceive engineering as being an "pure" science because they do not see the relevance of these courses to their needs and interests in engineering (Besterfield-Sacre, et. al., 1998). Some researchers have proposed integrated curricula where science courses are instructed together with engineering components (Schneck, 2001; Froyd & Ohland, 2005). It has been shown that new curricula emphasized fundamental relationships among subject areas are able to improve student learning satisfaction significantly. Improved curricular placing emphases on problem-solving, technical writing, team work are also proven to be effective in helping students to overcome the barriers associated with relevance (Besterfield-Sacre, et. al., 1998; Bernold, et. al., 2000; Dichter, 2001: Dym, et. al., 2005).

Overall college environment. Elements like social support, staff support, interaction with faculty, opportunities of involvement in research, cultural atmosphere of institutions, etc. form an overall college environment. Research findings have shown that overall college environment plays an important role in students' retention (Astin & Astin, 1992; Astin, 1993; Shuman, et. al., 1999; Buyer & Connolly, 2006). For example, student-faculty interaction is significantly correlated with college GPA, college retention, graduating with honors, and enrollment in graduate school. Effective student-faculty interaction can take many forms (Kuh & Hu, 2001). Interaction in classroom includes discussion on course-related topics or offering academic advice. Interaction out of classroom includes conversations on non-academic related topics, or faculty-supervised internships and research opportunities. In particular, Bjorklund, et. al. (2002) has recommended student-faculty communication through integrating design projects and collaborative learning opportunities in classroom teaching. They have found that more student-faculty interaction also promotes student gains in engineering design and professional skills, in addition to retention and academic success. Astin and Astin (1992) have shown that interaction opportunities like assisting faculty in teaching courses and involving in faculty research projects enhance students' satisfaction with engineering courses, with faculty and overall institutional experience. They have argued that if faculty is less involved in teaching/advising students, and students get little support and encouragement from faculty role model, it leads to significant negative effects on students' satisfaction. In this context, large institutions where little student-faculty interaction is encouraged tend to have negative effects on student persistence (Astin & Astin, 1992). Strong competition from highly selective institutions also tends to reduce persistence

(Astin & Astin, 1992). As Tinto (1987) summarized, the academic and social characteristics of an institution help to shape students' commitment to an educational goal and commitment to remain with the institution.

2.2.2. How do the cognitive characteristics affect the outcome of engineering education?

Cognitive ability has long been considered as the most important criteria in college admission and college success. Therefore the relationship between cognitive characteristics and educational outcome has been the most widely studied topic on research about college success. The characteristic drawn the most attention in this category is academic ability. Other cognitive characteristics that have significant impact on academic results such as self-efficacy, learning styles and study skills have also interested researchers frequently.

Academic ability. Many research findings have proven that academic ability is strongly correlated with admission and retention in engineering schools. For example, Astin and Astin (1992) have shown that mathematical and academic preparations are the strong indicators to students' initial interests in engineering majors and careers. Academically well-prepared high school students are more likely to be recruited into engineering majors. Students' entry level of mathematical and academic competency is the strongest and most consistent predictor of persistence in engineering program (Astin & Astin, 1992; Moller-Wong & Eide, 1997; Nicholls, et. al., 2007). In particular, French, et. al. (2005) have pointed out that SAT mathematics and verbal scores and high school ranking are good predicators for college GPA, and college GAP is a subsequent good predictor for persistence in engineering. Like Shuman, et. al. (1999) pointed out, about a fourth of the freshmen and a third of the upper class students have to drop out engineering due to poor GPA.

However, not all researchers believe that the two traditional measures of success in college, i.e., GPA and academic ability, are good predictors of retention. They argue that there is little difference in academic ability between students who persist and who do not. As Tinto (1987) has pointed out, most students who drop out of college actually withdraw voluntarily. Seymour and Hewitt (1994; 1997) have showed that many students who leave engineering are actually competent to complete STEM majors. This argument is supported by their measurement result showing that the average GAP of women who leave STEM majors is actually higher than the average of men who stay. In fact, Moller-Wong and Eide (1997) have found that very high composite scores and a greater than average number of semesters of high school English and art are good predictors for attrition, rather than retention, from engineering. Researchers in this group tend to believe that students leave engineering due to non-cognitive related reasons such as lack of motivation and interests rather than failing grades (Levin & Wyckoff, 1988; Besterfield-Sacre, et. al., 1997; 1998; Bernold, et. al., 2007). More discussion regarding non-cognitive characteristics will be detailed in the later section.

Self-efficacy. Self-efficacy is defined as the thoughts that students hold about their abilities in performing tasks necessary to achieve a desired outcome (Bandura, 1986; 1997). The discussion in this paper takes Bandura's stand that self-efficacy is a cognitive associated attribute while self-confidence is more an affective associated attribute. Therefore the discussion on effects of self-efficacy is presented in this section, while the effects of self-confidence will be discussed under the category of affective characteristics.

The impact of self-efficacy on recruitment and retention in engineering majors is found to be significant. At the high school level, self-ratings of mathematical ability, computer skills and academic ability are found to be good indicators for predicting STEM enrollment, while needing remedial lessons in mathematics is a good indictor for non-STEM orientation (Astin & Astin, 1992; Nicholls, 2007). Based on an instrument designed to measure factors that influence self-efficacy beliefs of engineering students, it is found that motivation, understanding of the learning material and computing abilities are the most influential ones in boosting engineering students' self-efficacy (Hutchison, et. al., 2006). This measurement instrument has also indicated that factors like teaming skills, availability of help and ability to access the help, ability of completing assignments, problem solving skills, enjoyment, interest and satisfaction in learning, and grades are strongly correlated with positive self-efficacy. Many research results have also indicated that there are statistically significant differences in self-efficacy between gender and ethnic groups. More details will be discussed the demographic category later.

Learning styles. Student learning temperament types are found to have significant correlation with success in engineering education. For example, Bernold et. al. (2007) have found that students who like to ask questions such as "why" and "what if" tend to struggle with lower GPA and have higher attrition in engineering schools. The why-type students appear to have difficult time in traditional lecturing environment in engineering schools since they thrive more in environments encouraging divergent thinking, opinion generating and subjective interpretations. Likewise, the what-if-type students also encounter difficulty a "chalk-and-talk" lecturing style used in most engineering classroom since they are more oriented toward creativity and originality and prefer a hands-on learning environment. Felder, et. al. (2002) have argued that thinker-type students usually do better in relatively impersonal engineering environment, while feeler-type students are more likely to drop out of engineering majors because they tend to value more socially important works. Intuitor-type students prefer creative and innovative works more than sensor-type students to, and the "intuitors" also tend to obtain higher GPA than those "sensors" in engineering schools. These results have revealed that we need to change the traditional engineering teaching methodology in order to retain students with disadvantaged learning styles in the current learning environment.

2.2.3. How do the affective characteristics affect the outcome of engineering education?

Education is an aggregate of both intellective and non-intellective processes. If a student has formed negative attitudes towards engineering, he/she might choose to leave regardless of the good academic standing. Ever since the publication of Daniel Goleman's first book on emotional intelligence in 1995, the impact of affective characteristics on college success has received extensive attention in engineering education.

Attitude. Research findings have revealed that attitude is both a good predictor to explain the variations of GPA in engineering students (Levin & Wyckoff, 1988) and a strong indicator for retention in engineering schools (Woods & Crowe, 1984). Many incidents occurred during the educational process could be responsible for forming a student's negative attitude towards learning. If students have negative impression of engineering education or engineering profession, they may switch out from engineering majors (Seymour & Hewitt; 1997, Besterfield-Scare, et. al., 1997; 1998; 2001). When students have less enjoyment in studying mathematics and science, or dislike the teaching methods in engineering, they appear to have high attrition rate (Besterfield-Scare, et. al., 1997; 1998; 2001; Seymour & Hewitt, 1997; Bonous-Hammarth, 2000). Students come to engineering schools with various expectations such as to gain a general education, to prepare for graduate study, to get a better job with more pay, and so on. If the actual experiences in engineering colleges do not match their initial expectations, negative attitudes will emerge and attrition will occur (Astin & Astin, 1992; Shuman, et. al., 1999). The set of perceived attitudes about engineering that students bring with them into the first year of college will potentially affects their perceptions of engineering, motivation to learn, self-confidence, competency, performance, and eventually retention. The attitudes developed during college years will affect in the long run their awareness of contemporary engineering issues, understanding of the impact of technology on the advancement of society and engagement in life long learning (Besterfield-Scare, et. al., 1998).

Self-confidence. The correlation between students' self-confidence in engineering and retention rate in engineering schools is found to be high. Leslie, et. al. (1998) have showed that students' self-confidence in solving problems in engineering and science is a good predictor for successfully graduating with a STEM degree. Besterfuekd-Sacre, et. al., (1997; 1998) have further pointed out that as long as students have "low confidence in their engineering skills and basic engineering knowledge" as well as "poor perceptions of their own academic abilities", they are likely to switch from engineering to other majors despite their good academic standing.

Early commitment. Another important indicator for students' persistence in engineering is their initial engineering career aspirations (Astin & Astin, 1992, Shuman, et. al., 1999). Research findings have suggested that students who are unsure about completing the engineering program when entering into engineering schools are likely to switch to other majors. In fact, there is clear evidence that students who left in good academic standing started their undergraduate careers with less commitment to engineering than those who remained in the program (Besterfuekd-Sacre, et. al., 1997; 1998). The persistent students are usually those who initially focus on engineering, work hard academically, and have very few outside diversions. Measurement results have also indicated that at the later stage along the engineering educational pipeline, STEM majors attract almost no newcomer and mainly retain the old adherents (Hilton & Lee, 1988). Therefore, it is important to encourage more students to make commitment to STEM majors in the early stage, when curricular options are still available and mobility is not discouraged.

Motivation. Motivation has been identified as an important characteristic predicting engineering retention (Felder, et. al., 2002). Qualities like persistence, resilience and clear goal setting are critical in motivating a student's commitment to graduate. Most of the research studies in engineering education have been focused on the effect of goal setting on educational outcome because personal goal offers direct insight into how students think about their futures. Nicholls, et. al. (2007) have found that STEM students tend to set their future goals on making a theoretical contribution to science and engineering, while non-STEM students tend to set their goals on influencing social values. In particular, as Astin and Astin (1992) have pointed out, non-STEM oriented students tend to place more value on personal goals related to money and status. Business major seems to be a popular choice for transferors from STEM, especially engineering majors. These results have informed us that the social values and personal benefits of receiving engineering education need to be emphasized during the educational process.

2.2.4. How do the demographic characteristics affect the outcome of engineering education?
Demographics refer to selected population characteristics. Engineering students' learning performance is shown to have strong correlation with the population group they belong. Among the long list of variables commonly included in demographic data, correlations of gender and ethnicity on educational outcome have received most attention.

Gender. A considerable number of research studies have addressed gender issues in STEM education. A general conclusion is that women are slightly more likely to defect from engineering majors/careers across all ethnic groups (Astin & Astin, 1992; Smyth & McArdle, 2004), with female African-American, Native American and Hispanic/Latino students exhibiting the largest drop in STEM majors (Bonous-Hammarth, 2000). One of the main reasons responsible for the higher attrition rate in female engineering students is that they commonly show a low self-efficacy in their STEM abilities (McIlwee & Robinson, 1992; Grandy, 1994; Brainard & Carlin, 1998; Besterfield-Sacre, et. al., 1997; 1998; 2001; Baker, et. al., 2007). For example, females have a low tinkering self-efficacy due to their lack of experience in using tools and machinery, taking things parts and fixing components together (McIlwee & Robinson, 1992). Further, female engineering students usually have low technical self-efficacy in believing their competence to learn and apply engineering knowledge and skills. Last but not least, their self-assessment as problem solvers and future engineers is also lower than male engineering students (Grandy, 1994). Apart from having low self-efficacy, having doubts in the societal relevance of engineering has withdrawn women from engineering. Most women do not consider engineering as a viable career choice because they believe it is incompatible with their interest and ability in improving individual lives and benefiting society through designing engineering products (Seymour & Hewitt, 1997; Adelman, 1998; Meinholdt & Murray, 1999; Besterfield-Sacre, et. al., 1997; 2001; Baker, 2007). Furthermore, the capacity of prevailing sex-role definitions to discourage the potential candidates among women from attempting a scientific career is responsible for the under representation of women in science (Bar-Haim & Wilkes, 1989). The above research findings have suggested that it is not the cognitive ability or academic performance but rather the psycho-social factors that have drawn female students away from engineering majors and careers.

Nevertheless, female is not always a consistent negative indicator for graduation in engineering majors (Zhang, et. al., 2004). Hilton and Lee (1988) have found that although the proportion of women is considerably lower at each time point in the educational pipeline, the persistence rate is higher for women than men, which is different from the above observation. Besterfield-Sacre, et. al. (2001) have found that female engineering students' rating on study skills is higher than their male counterparts. Astin and Astin (1992) have indicated that a female student with a high SAT math score and a strong science orientation is a good indicator for enrollment for engineering majors. Sax (1996) has also shown that a female student with the motivation of making a theoretical contribution to science is the best predictor of enrollment of a STEM graduate degree. Some researchers believe that, through well designed intervention programs, female students' tinkering and technical self-efficacies and their belief in societal relevance of engineering can be increased to make a difference in their attitudes towards these traditionally male dominated fields (Baker, et. al., 2007).

Ethnicity. In order to encourage more under representative ethnic groups to join engineering, studies on ethnic characteristics have drawn great attention in recent years. The general finding from many investigations on educational outcome of minority students majored in STEM degree is that minority is a significant indicator of attrition in STEM majors (Seymour & Hewitt, 1997). In particular, female African-American, Native American and Hispanic/Latino students exhibit the largest drop in STEM majors, while male students in these ethnic groups experienced the second largest dropout rate (Bonous-Hammarth, 2000). However, there are controversial measurement results. For example, (Astin & Astin, 1992) have found that White students show the largest attrition rate from scientist-practitioner careers than other ethnic groups.

Comparative studies of all the ethnic groups have shown that African-American and Hispanic students enter into engineering studies with statistically significantly higher impressions about engineering than other ethnic groups (Moller-Wong & Eide, 1997; Besterfuekd-Sacre, et. al., 1998). These groups also tend to enjoy working in teams more than other groups. However, African-American and Asian-Pacific students' self-assessments of their engineering abilities decrease significantly during the first year. Among all ethnicity groups, the characteristics of the Asian-American group are noteworthy. This group is likely to express initial interest in STEM and show least attrition rate (Hilton & Lee, 1988; Astin & Astin, 1992). Smyth and McArdle (2004) have also pointed out that Asian-American students are more likely to graduate with a STEM degree, while under-representative minority students are less likely to obtain a STEM degree.

2.3. What Data Collection and Analysis Methods Have Been Applied?

Apart from identifying the significant indicators and raising the meaningful research questions, the other critical tasks in measurement of students' characteristics involve designing the proper methodology for data collection and choosing the suitable approaches for data analysis. The frequently applied data collection and analysis methods in the discussed literature are summarized below. For the succinct presentation purpose, for each method, only representative examples are referenced in this section.

2.3.1. Data collection methods

In social science research, the typical data collection methods are focus group, open-ended survey and closed-form questionnaire. These methods are not applicable to solve engineering problems, however, they are appropriate to be applied in research of engineering education.

Focus group. Focus group is a commonly used method for collecting exploratory and exhaustive information about a particular issue. There are several advantages of using focus group method (Krueger, 1988). First, it allows a researcher to capture the "real-life" data by providing an environment for face-to-face discussion. Second, a particular issue can be discussed in depth through the flexible structure of this research method, while this is usually not possible in a fixed structure design. Third, this research method costs less and generates result more efficiently as compared to other measurement methods. However, focus group method is not applicable when statistics are needed. When the research topic involves emotional issues, this method is also not suitable. Further, the first hand data is not always obtainable because some members may not express the true feeling in the presences of others. Finally, the results of the measurement can not be generalized to the whole population due to the limited sample size. Many research studies reviewed above have applied focus group. Here only two examples are listed. Besterfielf-Sacre, et. al. (1998) used focus groups to identify students' attitudes towards engineering and perceptions about their engineering abilities. Ohland, et. al. (2004) applied this method to measure students' perspectives on their experience of taking the new engineering entrepreneurs program.

Open-ended survey. Open-ended survey allows respondents to answer questions in their own words. There is no definite answer to an open-ended survey question. When the subject of concern is complex with a number of avenues to explore, open-ended survey method allows more in-depth information to be obtained about a sensitive subject in a more private setting. However this method is more time and effort costly as compared to focus group or closed-form questionnaires because it involves qualitative analysis. Similar as the focus groups method, it is difficult to statistically analyze data obtained via open-ended survey method. Qualitative summaries are usually produced with little or no generalizable statistics. The representative examples are given below. As part of the process of transferring out of engineering programs, students are required to complete an open-ended exit survey. Besterfielf-Sacre, et. al. (1998) implemented an open-ended survey to understand the reasons why students chose to leave engineering programs in their attitude assessment study. Seymour and Hewitt (1997) used an open-ended survey to measure various characteristics, including reasons for leaving STEM, intrinsic interests in learning STEM, learning styles, etc.

Closed-form questionnaire. If statistical inference results are desirable, the closed-form questionnaire method provides a practically efficient measurement instrument for evaluating characteristics of engineering students. Closed-form questionnaire method adopts rating scales, check lists, semantic differentials and so on to measure respondents' opinions about a particular subject. This method is less expensive and time costly as compared to focus group method and open-ended survey method. It is therefore suitable for analysis that needs a large data set. However, due to the limitation of the response choices, this method usually provides less detailed data and thus is not suitable for exploration of complex issues. Since most all of the research studies reviewed in this paper have applied this method to measure various characteristics of engineering students, examples will not be listed here.

2.3.2. Data analysis methods

This section provides an overview of the data analysis methods used in current literature studying the measurement of the characteristics of engineering students.

Logistic regression. This method is often used in research studying prediction of college enrollment, retention and graduation (Besterfielf-Sacre, et. al., 1997; 1998; Wong-Moller & Eide, 1997; French, et. al., 2005; etc.). The status of enrollment, retention and graduation is usually coded as a dependent dichotomous variable, i.e., enrolled/retained/graduated = 1, not enrolled/not retained/not graduated = 0. The identified significant characteristics are normally fitted into a logistic regression model as independent variables to predict enrollment, retention and graduation. Wong-Moller and Eide (1997) extended their analysis a step further from logistic regression. They calculated the predicted probability of a student belonging to a particular risk category. Instead of predicting the dichotomous status of being successful and failure, this method tells the probability that a student might graduate from engineering.

Stepwise/Hierarchical multiple regression. Predicting college success usually involves many influential variables. To identify the significant characteristics, stepwise multiple regression is a commonly used method in existing research. In stepwise multiple regression, groups of characteristic variables are entered into the regression model sequentially as blocks according to their sequence of occurrence or logic. Groups of variables are entered in this stepwise fashion until no additional variables are capable of producing a significant reduction in the residual sum of squares of the dependent variable. The examples of research using this method for data analysis in the reviewed literature include Zhang, et. al., (2004), French, et. al. (2005), etc.

Covariate adjustment. Broadly speaking, students' college success depends on two factors, i.e., students' background and their preparation at entry level, and university factors. Different types of university programs tend to in take students who are different at the beginning level. The successes of the university programs may not necessary reflect the differential impact of these programs, but simply the differences in the characteristics of the entering students in these different programs. Therefore, if a study is to exam the success of a university program, then students' entry factors need to be partialed out as covariates. Typical examples applied covariate adjustment are given in Astin and Astin (1992); French, et. al., (2005).

Longitudinal data analysis. Education is a progressive process. It thus makes sense to monitor students' educational performance and predict their status in a longitudinal manner. Longitudinal data analysis (LDA) is another widely used method in existing research. Typical applications appeared in studies by Moller and Eide (1997), Bernold, et. al., (2007), Zhang, et. al., (2007), etc. In these studies, students' background data like ACT and SAT scores, high school ranking, learning types were first measured at the entry point. While in the program, typically at the end of the first semester and the end of the first year, students' academic performances like GPA, cumulative GPA, number of credits enrolled in each term, etc., were measured again. Data collected at these different time points were then used for a longitudinal data analysis to predict their educational success.

Two-step design. Many indicative characteristics are found to be significant in predicting college success. When analyzing data containing demographic, academic performance, attitudinal information across a wide range of students, a "two-step design" is an effective approach to be applied. The first step involves applying basic statistical tests to the data set to identify the most consistent predictive indicators among a large group of variables. In the second step, the highlighted indicators are then used as inputs for more sophisticate models for further identification of significant predictors for college success. For example, Nicholls, et. al., (2007) examined a large data set with approximately 300 variables by using the two-step design.

Exploratory factor analysis. Measurement of characteristics of engineering students involves studies of many latent constructs. For example, constructs like external influence, cognitive factor and attitude factor are all not directly measurable. The behavior of these latent variables can only be indirectly estimated through their effects on their manifest variables. Exploratory factor analysis (EFA) can be applied to reveal the construct structure from the observed data. This method is especially suitable when researchers have no hypotheses about the nature of the underlying construct structure of their measure. For example, Li, et. al., (2008) applied an EFA to study the perspectives of engineering among college students. The EFA result led to a four-construct structure of their observed data. The construct "interest" is found to exhibit most significant difference between engineering and non-engineering students.

Structural Equation Modeling. Structural equation modeling (SEM) also provides an effective tool to estimate a structural model in a complex measurement situation when latent constructs are involved. For example, Cabrera, et. al., (1993) established a SEM model to predict the commitment to institution and persistence via latent constructs on environmental facts, academic integration, social integration and financial attitudes. French, et. al., (2003) developed a SEM to predict GPA, institution/major enrollment based on latent constructs like faculty-interaction and motivation, and measurable constructs like high school ranking and SAT scores.

3. What Needs to Be Done?

This paper has classified engineering students' characteristics studied in current literature into three categories, i.e., external characteristics, internal characteristics, and demographic characteristics. Although the more sophisticate research studies have measured characteristics across all the three categories, it lacks a comprehensive model that is able to exam all the significant characteristics in all areas systematically and quantitatively. Short of such a model leads to an incomplete quantitative explanation of the overall impact of these characteristics on college success in engineering schools. Therefore we need to develop a comprehensive model for the identification of the most significant characteristics in the overall framework defining characteristics of engineering students.

So far, a considerable amount of research efforts have been spent on studying the difference in the external and internal characteristics among comparison groups on ethnicity, gender, institution, etc. However, no comparative studies have been conducted on engineering students' characteristics across different cultures and nations. In the globalization era, multi-national manufacturing company is a well accepted enterprise concept. Outsourcing manufacturing jobs from labor expensive countries to labor-inexpensive countries is a common practice in manufacturing industry nowadays. Engineering in a multinational company has become a joint practice cooperated by partners from different cultures and different countries. Engineering education needs to be changed to better prepare students to work in a globalized manufacturing environment. Hence there is a need to study engineering education from the globalization perspective. Comparative research on engineering education should not be restricted within the traditional comparison themes.

4. Conclusion

This paper has reviewed the measurement of characteristics of engineering students in literature published in the past two decades. Although widely discussed, there is no universally agreed upon definition of engineering students' characteristics. This review has suggested that students' characteristics can be defined under external, cognitive, affective and demographic categories. The review results have revealed that, apart from academic performances, many non-cognitive characteristics have equally significant impact on college success. To attract and retain more qualified students into engineering education needs a joint endeavor from various aspects in engineering education, including instilling positive impression of engineering from K-12 education, enhancing college interaction, improving curriculum, modifying teaching methodology and so on. From the measurement perspective, this study has suggested that more efforts need to be placed on developing a systematic model to exam the significance of all the characteristics on college success. In the globalization and internet era, cross-cultural studies on engineering students' characteristics is also an important topic to be addressed in future.

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