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# A Model for Freshman Engineering Retention

CINDY P. VEENSTRA
Veenstra and Associates

ERIC L. DEY
School of Education
University of Michigan

GARY D. HERRIN
Industrial and Operations Engineering
University of Michigan

## ABSTRACT

**With the current concern over the growing need for more engineers, there is an immediate need to improve freshman engineering retention. A working model for freshman engineering retention is needed. This paper proposes such a model based on Tinto's Interactionalist Theory. Emphasis in this model is placed on pre-college characteristics as predictors for student academic success and retention. Through a literature search of both engineering education and general empirical studies, a list of significant pre-college characteristics important for modeling freshman engineering student success and retention was developed. Significant differences were found between the engineering education and general empirical studies. The final model is described in terms of a block diagram with an extension to statistical modeling. Tables of empirical studies that have included pre-college characteristics as predictors for student success and retention are included. An application using data from a University of Michigan study is discussed.**

**Keywords:** freshman engineering retention, student retention model

## I. INTRODUCTION

In the engineering education literature, a collection of empirical studies of engineering student retention has been presented. Streveler and Smith [1] brought to the attention of the engineering community the need for a theoretical basis for studies in engineering education. As an application of this need, a freshman engineering student retention model that encompasses most of these empirical studies is needed. This paper proposed such a model. The emphasis of this model is on the use of pre-college characteristics to predict first year academic success and retention.

Educators have proposed models of college student retention, of which the most tested and accepted is that of Vincent Tinto [2]. Using Tinto's Interactionalist Theory as a basis, a model of engineering student retention will be proposed. It has a strong theoretical basis in education. This proposed model will take into consideration the significant differences between a general college education and that of an engineering education. In addition, the proposed model will include significant pre-college student characteristics for the prediction of student success or retention from a review of empirical studies.

A model of engineering student success and retention is developed in this paper and is based on:

- A review of engineering education models and general education models
- A discussion of the differences between a engineering education and non-engineering education
- A review of engineering education and general empirical studies to establish a list of dominant pre-college characteristics important for student success and retention in engineering colleges
- A review of the characteristics needed by an engineering graduate based on *The Engineer of 2020* [3]

Together, the final model presents a literature-based model for freshman engineering retention. This model is applicable for first-time full-time freshmen entering engineering colleges. While it is intended as a model for freshman engineering retention, the model may well be applicable as a model for general college retention among freshman.

## II. CONCEPTS LEADING TO THE DEVELOPMENT OF THE MODEL

### A. Prior Engineering Student Retention Models

Some discussions in the engineering education literature have helped shape the proposed model of engineering student retention. The student attrition away from engineering has been described as a "pipeline" and "path" analysis. The pipeline model envisions a leaky pipeline with the leaks representing attrition from middle school to graduation from an engineering college. An example of this model is discussed in Johnson and Sheppard [4]. They looked at the pipeline structure of the high school senior class of 1990 (nationally) as students from that class made decisions to go to college, enroll in an engineering college and graduate. Of the 1990 high school senior class, 87% graduated from high school, 28% enrolled in 4-year colleges and only 2.3% enrolled in engineering programs, with only 1.6% graduating with an engineering degree. Their review of studies led them to state, “HS [High School] preparation and lack of finances are two key factors that cause the differences in the enrollment rates between underrepresented minority students and other populations.” Adelman proposed that the correct model was not a pipeline but a path model [5]. The courses taken in high school in math and science are similar for both engineer and science/math majors. Since the freshman courses in engineering include chemistry, physics and math, students may switch to a science major with little loss of time in major. He sees the decision as a competitive one among several choices. One such competing interest is business, which often attracts students who choose to leave the field of engineering.

Watson and Froyd proposed a model of a transmission line with three component lines [6]. The three component lines would include cognitive ability development, occupational choice development and self-identity development. As with transmission line structures, they see that each of these areas has an interference field associated with it. One field could affect the transmission of another line (area) if one of the areas is not sufficiently developed. For example, if a minority student must spend a lot of energy in establishing his/her self-identity in the engineering college, it may influence cognitive ability development (i.e., doing well in the 1st term courses).

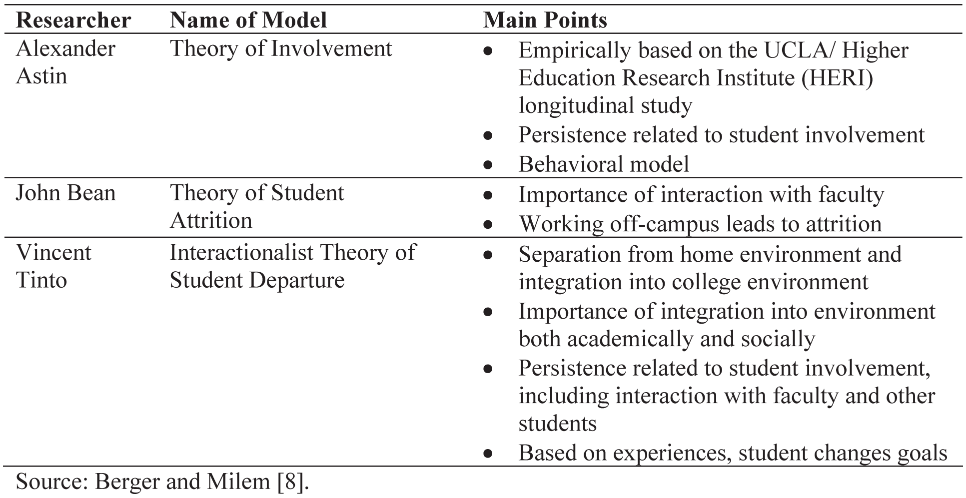
It is difficult to develop a statistical model from the pipeline model, Adelman’s model or Watson and Froyd’s model. As an alterative, the models from education (general college) research were investigated for a model that could be applied statistically. This is discussed in the next section.

### B. General College Retention Models

Education researchers have developed the most comprehensive models on general college student retention. The more complete and discussed models include Tinto’s Interactionalist Theory, Bean’s Theory of Student Attrition and Astin’s Theory of Involvement model. A summary of these models are presented in Table 1. These models tend not to differentiate among the liberal arts programs, the STEM programs or the engineering programs; the same theory or model is used for all. These models of why students leave college without a degree are extensive and are based on theories in four disciplines: economics, psychology, sociology and organizational models [7]. Therefore, they provide a theoretical basis for a model.

### C. Contrasts between Engineering Education and other Freshman College Programs

Tinto developed his model for general college education. Could Tinto’s model be inclusive of engineering education? Are there major differences between an engineering education and general college education? These questions need to be addressed to understand more completely the education process in the development of a model for freshman engineering retention. First, a general



| Researcher | Name of Model | Main Points |
|---|---|---|
| Alexander Astin | Theory of Involvement | • Empirically based on the UCLA/ Higher Education Research Institute (HERI) longitudinal study<br>• Persistence related to student involvement<br>• Behavioral model |
| John Bean | Theory of Student Attrition | • Importance of interaction with faculty<br>• Working off-campus leads to attrition |
| Vincent Tinto | Interactionalist Theory of Student Departure | • Separation from home environment and integration into college environment<br>• Importance of integration into environment both academically and socially<br>• Persistence related to student involvement, including interaction with faculty and other students<br>• Based on experiences, student changes goals |

Source: Berger and Milem [8].

***Table 1. Summary of Education Models on Retention.***

college education will be discussed and compared to pre-professional and professional programs; then engineering will be discussed as a professional program (in the freshman year).

The role of a general college education is broad, based on the learning in the literatures, humanities and sciences. The term, Literature, Arts and Science (LSA) education, will be used to recognize this education in the liberal arts and sciences. Of these majors, science and math majors would enroll in similar freshman courses as engineering majors. In contrast, liberal arts majors would take mostly literature, humanities and social sciences in their freshman year.

The role of all pre-professional and professional programs at the undergraduate level is to prepare a student for a specific career. Included in this category would be engineering, education (teacher), business, pre-medicine, and pre-law. All may be similar in that they have an introductory freshman course in their discipline.

Some of these pre-professional and professional programs have a closer freshman curriculum to engineering than others. For example, both engineering and pre-medicine require enrollment in science courses and math courses (either calculus or statistics) in the freshman year. In contrast, pre-law and business would have more focus in the social sciences in the freshman year.

To understand the engineering curriculum, it is important to understand the role of engineers in society. In becoming a competent engineer, the function of an engineer in society can be thought of as a designer of a new product or system or problem-solver. Typically, engineers are involved with defining or using the latest technology. Engineering is also seen as the profession that will create the latest innovation in technology. Engineers are seen as innovation-makers. In manufacturing, this includes designing the manufacturing processes that will enable the design to be manufactured. In quality engineering, this includes designing the processes (both technical and human interfaces) that assure that the manufactured product meets the design's intent. In support of these ideas, the National Academy of Engineering published *The Engineer of 2020* [3] and proposed that the following would be key attributes of an engineer:

- Strong analytical skills
- Practical ingenuity
- Creativity (invention, innovation, thinking outside the box, art)
- Good communication skills
- Master principles of business and management
- Leadership
- High ethical standards
- Dynamism, agility, resilience, flexibility
- Lifetime Learners

In summary, an engineering student is preparing for a career as an analytical thinker who can lead people in technology innovation, design and systems thinking. From the college curriculum, the courses most strongly related to analytical thinking are mathematics and science courses. The engineering freshman curriculum is weighted with mathematics and science courses.

Student success and retention rates of freshman engineering students is expected to be closest to that of science and math majors since science and math majors take the same freshman level courses as engineering students. Differences between these two student groups is that engineering students take freshman engineering classes, which also has a high math and science content.

More differences in the freshman curriculum would be expected comparing engineering students to pre-med students (fewer math and science courses, more humanities) and the largest difference would be seen between engineering students and liberal arts majors (almost no math and science courses).

In summary, an engineering education is considered uniquely different from the other pre-professional or professional programs or the LSA majors, leading to different retention issues. Based on this, four main differences are hypothesized between the engineering freshman curriculum and other freshman programs that affect the development of a model of engineering student retention:

1. A major in engineering prepares a student for a specific career, that of an engineer; the other pre-professional and professional programs also prepare a student for a specific career in their program. Majors in the liberal arts or sciences are less focused on a career, especially in the freshman year.

2. Focus of the freshman engineering curriculum will be on developing strong analytical skills and problem-solving using technology; the engineering curriculum is the most demanding for freshman math and science courses.
3. Expectations for admissions to an engineering program will include a wide range of college-prep courses with a high concentration of math and science courses (due to the need to develop analytical skills). Expectations for admissions to a LSA program and the other pre-professional programs will include a wide range of college-prep courses in high school.
4. An engineer will be expected to add value with his/her designs and because of the perceived competitive nature of design, have the skills to lead a team in continuously improving the product or process. This is specific to the engineering career. In addition, Seymour and Hewitt [9] have discussed the weeding-out system that is common in engineering colleges. As a result of both expectations of a career that requires a competitive behavior and a weeding-out tradition of engineering colleges, the freshman engineering curriculum tends to be competitive, leading to a lower first year average GPA. Astin [10] found that engineering students earned lower college GPAs than other students. Students with a stronger math and science background will have a competitive advantage whereas students with a weak math and science background may have a competitive disadvantage. This can lead to a higher percent of engineering students on academic probation after the first year compared to LSA majors and the other pre-professional and professional programs. Therefore, a systems approach must support engineering students in achieving academic success in the first term.

### D. The Need for a Model of Engineering Student Retention

Because of the differences between an engineering education and an education in the LSA disciplines, the general college retention models (Table 1) do not adequately address engineering student retention. **A model of engineering student retention is needed to specifically address the characteristics of an engineering education**. Either a new model can be developed or an existing model can be revised to accommodate engineering student retention.

### E. Important Elements of a Model

Why is it important to propose a model of freshman student retention? Clearly, a model is needed to understand and judge empirical studies. In addition, a model will guide institutional strategies for student success. Astin, in describing his Model of Student Involvement, supports these ideas when he described the functions of his model [11]. These functions included three elements that are particularly important in the development of a model of engineering student retention and an explanation for the need for a model. They are:

- It must be is simply described
- It "provides a context for understanding the diverse literature in this field because it seems to explain most of the empirical knowledge gained over the years"
- It is "a useful tool that can be used both by researchers, to guide their investigation of student and faculty development, and by college administrators and faculty, as they attempt to design more effective learning environments"

In order to describe the model simply, a block diagram will be developed; this block diagram can be easily extended to statistical modeling using independent and dependent variables. In addition, a model will be developed that is consistent with current empirical studies.

## III. DEVELOPMENT OF A MODEL OF ENGINEERING STUDENT RETENTION

### A. Tinto's Model is a Platform for Model

Among education researchers, Tinto's theory/model has been the most empirically tested, is the most accepted and has reached "paradigmatic stature" [2]. For this reason, in developing a model of engineering student retention, Tinto's model will be used as a basis and expanded to define a model of retention for engineering students. In his model that was developed in the 1970's and later revised to take into account the results of empirical studies, Tinto presented a process of adjustment of a new student to college [12–13]. Referring to Figure 1, pre-college characteristics including Family Background, Skills and Abilities and Prior Schooling are important predictors of success in college. Family Background includes social status, the education of the parents and community

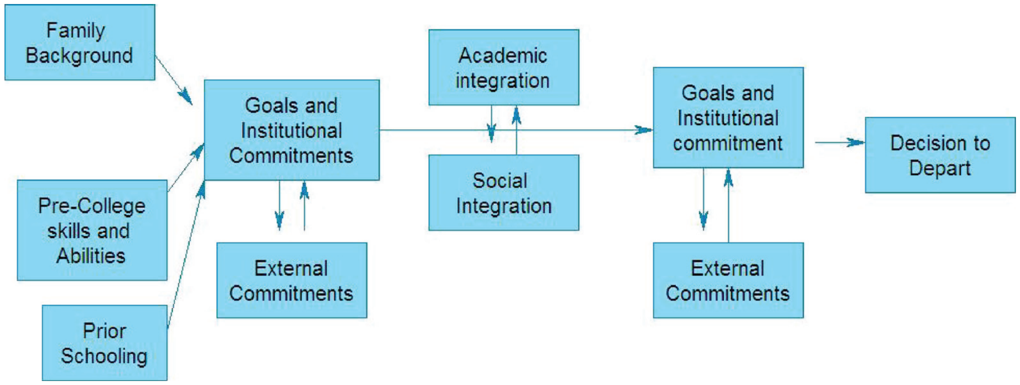


*Figure 1. Tinto's Interactionalist Model (adapted from [12]).*

size. Skills and Abilities include intellectual and social skills, financial resources, motivations and political preferences. Prior Schooling includes educational preparation and experiences. [12, p. 115] In his 2006 article, Tinto recognizes the recent empirical research that supports the importance of the support of the family in encouraging the student to continue in college [13].

According to Tinto's model, a student transitions from his/her family environment and then adjusts to the college culture. As he/she adjusts to college, a process of both academic and social integration is needed for the successful integration of the student. Academic integration is defined broadly as doing well in courses and social integration includes both social relationships with other students and discussions with faculty. As academic and social integration occurs, a student reaches a new level of learning. This level of learning translates into value-added education, student success and potential persistence. In this adjustment, a student comes to college with a set of career and college goals. As integration occurs, a student may change his/her goals for college with respect to a major or career.

Of major controversy in the Tinto model, is whether both academic integration and social integration are supported in the model by empirical studies. Braxton, in his review of Tinto's model with current empirical studies, found little support for academic integration but much support for social integration [2]. This is consistent with Astin's model on the importance of the involvement of the student in college activities [11]. Other empirical studies have found support for academic integration [14–17]. It is reasonable to state that a degree of both academic and social integration occurs. Since our new model is based on pre-college characteristics, the controversy is presented here but not of significant concern to our model.

### B. Literature Review Used to Develop Pre-College Characteristics

The general flow of the transition from high school to the freshman year in engineering is described in Figure 2. Of particular significance is the set of pre-college characteristics with which the student enters engineering college.

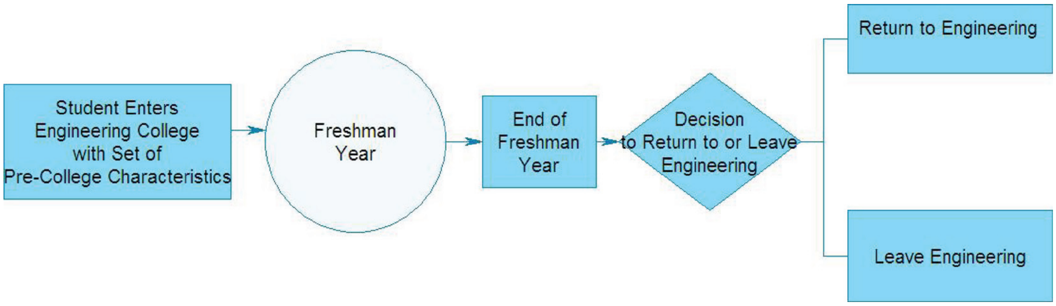
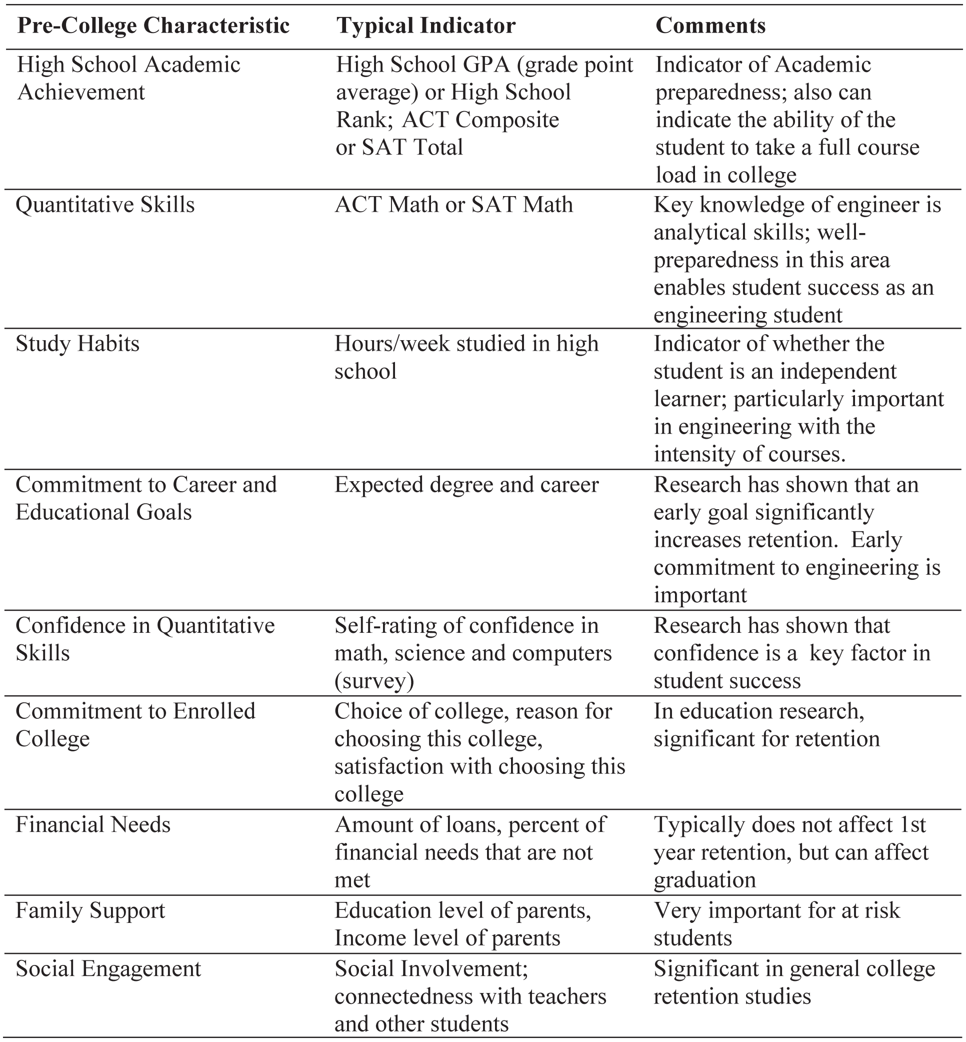


***Figure 2. Decision to Return to or Leave Engineering.***

A review of the literature was undertaken to summarize the pre-college characteristics that were found to be significant for first year student success (college GPA) and first year engineering retention. These pre-college characteristics were broadly categorized into nine basic categories of student success (See Table 2). In this review, a comparison of engineering retention empirical studies were compared to general college retention empirical studies for first year retention studies. Because of the small number of first year engineering retention studies found in the literature, a review of upper-class retention and graduation studies was also conducted. This effort was made to ensure



| Pre-College Characteristic | Typical Indicator | Comments |
|---|---|---|
| High School Academic Achievement | High School GPA (grade point average) or High School Rank; ACT Composite or SAT Total | Indicator of Academic preparedness; also can indicate the ability of the student to take a full course load in college |
| Quantitative Skills | ACT Math or SAT Math | Key knowledge of engineer is analytical skills; well-preparedness in this area enables student success as an engineering student |
| Study Habits | Hours/week studied in high school | Indicator of whether the student is an independent learner; particularly important in engineering with the intensity of courses. |
| Commitment to Career and Educational Goals | Expected degree and career | Research has shown that an early goal significantly increases retention. Early commitment to engineering is important |
| Confidence in Quantitative Skills | Self-rating of confidence in math, science and computers (survey) | Research has shown that confidence is a key factor in student success |
| Commitment to Enrolled College | Choice of college, reason for choosing this college, satisfaction with choosing this college | In education research, significant for retention |
| Financial Needs | Amount of loans, percent of financial needs that are not met | Typically does not affect 1st year retention, but can affect graduation |
| Family Support | Education level of parents, Income level of parents | Very important for at risk students |
| Social Engagement | Social Involvement; connectedness with teachers and other students | Significant in general college retention studies |

***Table 2. Pre-College Characteristics Important for Engineering Student Academic Success and Retention.***

the completeness of the model. Detailed tables of the empirical literature review are given in the attachments, Table A-1 and Table A-2. These tables are described in the Appendix.

A brief description of each category is given below with an explanation for its significance in the model.

***High School Academic Achievement:*** There was consistently strong support for the High School GPA and High School Rank from both engineering education empirical studies and general empirical studies and for both first year and four year studies. There was noticeably strong support for the ACT Composite and SAT Total and academic-related skills in the general college empirical studies. These are well-known as predictors in the literature [18]. It is logical that students who are well-prepared in the academics will have a higher success rate in college.

***Quantitative and Analytical Knowledge:*** As previously discussed, the role of the engineering college is to teach an engineering student to think analytically. As such, the more quantitative and analytical knowledge a student has upon entering an engineering college, the more prepared he/she will be for the intensity of the engineering courses. This knowledge includes trigonometry, calculus, the physical sciences and computer programming. Since some engineering colleges have "weeding-out systems" [9], the freshman year can be very competitive; thus a student, who is better prepared in quantitative and analytical knowledge, will have a high probability of student success. Finally, math and science preparation are consistent with the defined outcomes of *The Engineer of 2020* [3]. In support of these ideas, there was strong support for quantitative skills as a predictor of engineering success and retention in the engineering empirical studies. Strong support was found for the ACT Math and SAT Math scores as predictors in the engineering education empirical studies.

***Study Habits and Independent Learning:*** Taking into account the intensity of freshman engineering courses, it is a reasonable assumption that those students who are already independent learners with good study habits will earn better grades than those students who are not independent learners. The literature review of engineering education research showed that study habits and the number of hours/week a student studied in high school were important pre-college characteristics of success as an engineering student.

Tribus discussed the role of the professor and the student in his papers. As the professor becomes more of a facilitator of learning and the student becomes more of an independent learner, the student learns more. For an engineering education, Tribus indicates in his papers that being an independent learner is especially important. With increased autonomy, the student develops an attitude of "joy in learning" and intrinsic motivation [19]. Support for the importance of independent learning comes from Alexander and Helen Astin: "When students see themselves, or are viewed by others, as both learners and teachers, they take more responsibility for their own learning and help create more favorable learning environment for each other" [20]. University of Pittsburgh researchers found that good study habits contributed to student success and retention [17], [21–22].

From an institution's viewpoint, the more independent learners there are in the classroom, the easier it is to have student success for all students. For the first year of engineering college, a student who comes to college as an independent learner with good study habits has a higher probability of success.

***Commitment to Education and Career Goals:*** Students who are already committed to an engineering career as they enter engineering college should have a higher motivation for success. In support of this idea, Besterfield-Sacre et al. found that students who had a high impression of engineering and liked engineering as a career had a higher freshman retention rate [21]. In addition, it was found that there is a higher probability of a student graduating in engineering if his/her peers are in engineering [23].

***Confidence in Quantitative Skills:*** Motivation should also be high for students who have a high level of confidence in their pre-engineering abilities. Several engineering student retention studies have shown the importance of a high level of confidence in engineering skills or self-rating of engineering skills. In support of this, the Astin and Astin study showed that a high self-rating in mathematical skills was related to retention in engineering [23]. Using the PFEAS survey, Besterfield-Sacre et al. studied freshman engineering retention and showed that confidence in basic engineering skills increased freshman retention [21].

***Commitment to Enrolled College, Financial Needs and Family Support:*** Commitment to the enrolled college (i.e., this college is the first choice) should also improve retention. With the rising costs of tuition and housing costs at colleges, the ability of the family of a student to meet the financial needs is well-known as a significant variable for retention. In addition, a family's encouragement for a student earning a college degree is important.

Although there was strong evidence of commitment to the enrolled college and family support as predictors of retention in the education retention studies, there was minimal evidence of its importance in the empirical engineering studies. The education research first year retention studies showed "commitment to the university" as having a strong relationship to first year persistence [24]. This characteristic indicates how strongly a student wanted to come to this university (whether it was first choice). Retention studies, both engineering education and education, showed support for financial need as a predictor of student retention. This is more evident with the three- to four-year retention studies than the freshman retention studies. General college education studies have shown the importance of family support of students [12–13].

***Social Engagement:*** In the education literature, there is a significant discussion of the importance of social engagement, both from Tinto [12] and Astin [11]. Astin's Theory of Involvement stresses the importance of students becoming involved with activities within the university, including clubs and volunteer activities [11]. The more involvement, the more integrated the student becomes with the values of the institution. It can be hypothesized that students who have a high degree of involvement in clubs and volunteer activities in high school will continue their involvement in college. In their meta-analysis, Lotkowski et al. found a moderate relationship between social involvement (defined as "extent to which a student feels connected to the college environment, peers, faculty, and others in college, and is involved in campus activities") and college GPA and retention [25]. Because of the broadness of social engagement, different researchers use different measures of social engagement; as a result it is difficult to identify significant trends. The significance of social engagement is more evident in the general college research than in the engineering education research.

***Consideration of Gender, Race and SES:*** In developing a table of pre-college characteristics from a review of empirical studies, it was decided that a general model that could be used for all students was desired. As a result, gender, race and social-economic status (SES) are not listed as a separate pre-college characteristic. A framework for a model is desired so that an institution could use it to develop a strategic plan for success of all students. From a viewpoint of helping a student be successful in engineering college, the college can take no institutional action based on student's SES. (If financial aid is needed, the engineering college can provide a scholarship.) Tinto addressed this issue for colleges in writing: "Knowing about the role of family context may help institutions more effectively configure their support programs for differing student situations and populations. But it does not tell the institution either how to effectively tap into issues of family context or whether such actions, relative to other possible actions, are more likely to yield the outcome of increased persistence that is desired" [13]. Although SES was not considered as a separate category, segments of SES were included in "Financial Needs" and "Family Support".

### C. Final Model of Freshman Engineering Student Retention

The block diagram in Figure 3 is the basis for the proposed engineering student retention model.

It begins with the Pre-College Characteristics that a student brings to his/her first year experience in engineering college. Next in sequence is the Freshman Year Experience circle. This circle is envisioned to include both academic and social integration, consistent with Tinto's model. As the student transitions through the first year, he/she achieves "academic integration," i.e., either does well and meets his/her expectations or may do poorly. In many cases, social integration will contribute to academic integration. In the diagram, both academic integration and social integration lead to learning, which then leads to a level of student success, usually measured by the first year GPA. If the GPA is low, the student may be placed on academic probation and within a term or two, leave

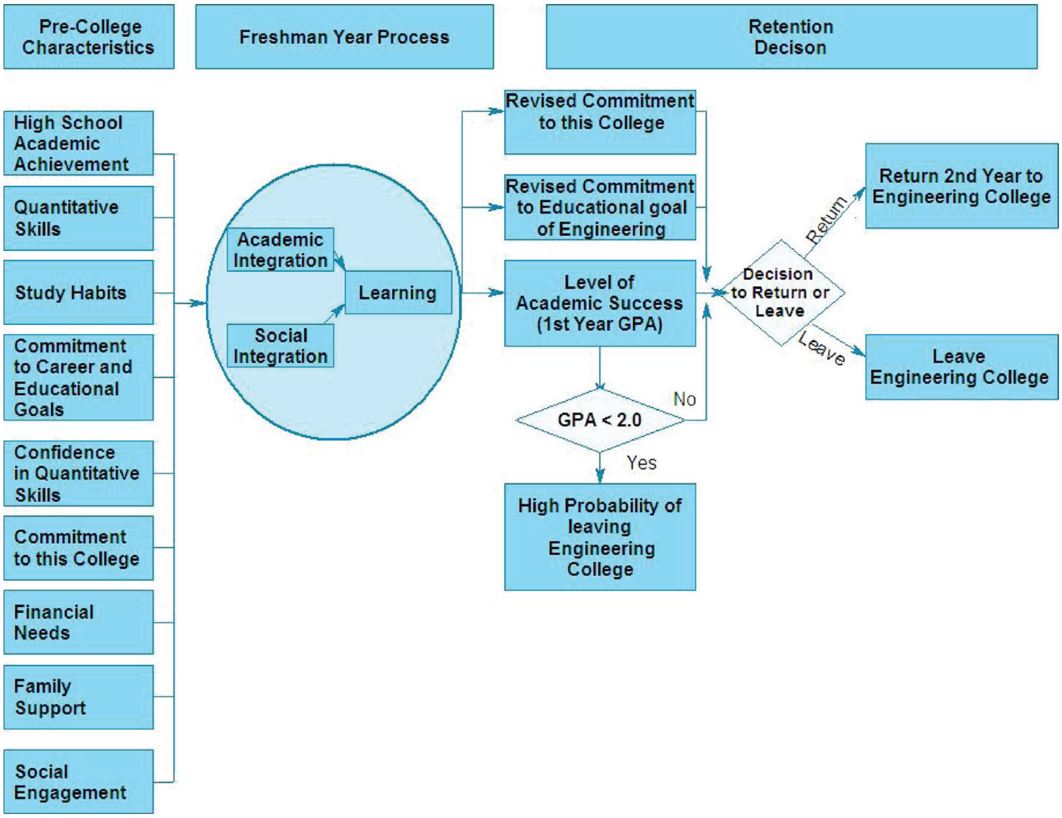


***Figure 3. Block Diagram of Model of Engineering Student Retention Block Diagram.***

due to poor academic performance. The GPA contributes to the student's decision on retention [26]. In this model, the GPA together with the revised commitment to an engineering goal and this particular college contribute to the student's final decision on retention. Either he/she decides to voluntarily return to or leave engineering.

This model is explained in more detail as follows:

***Pre-College Characteristics—Significant Findings:*** The pre-college characteristics are described in Table 2 and the literature review is presented in the Tables A-1 and A-2 attachments. Tinto's model strongly supports High School Academic Achievement (Prior Schooling), Commitment to Career and Educational Goals, Commitment to Enrolled College, Financial Needs and Family Support (See Figure 1).

A significant finding of a review of empirical studies on student retention showed differences between pre-college characteristics for engineering education studies compared to general college education studies (See Table 3). Most of the general college education empirical studies

| Pre-College Characteristic | Prevalent in Engineering Education Empirical Studies | Prevalent in General College Education Empirical Studies |
|---|---|---|
| High School Academic Achievement | X | X |
| Quantitative Skills | X | |
| Study Habits | X | X |
| Commitment to Career and Educational Goals | X | X |
| Confidence in Quantitative Skills | X | |
| Commitment to the Enrolled College | | X |
| Financial Needs | X | X |
| Family Support | X | X |
| Social Engagement | | X |

***Table 3. Comparison of Engineering Education and General College Education Studies.***

were consistent with Tinto's model. The most dominant pre-college characteristic defining this difference was Quantitative Skills. Consistently, the ACT Math or SAT Math was a significant predictor for academic success, as measured by the GPA, and for retention in the engineering education empirical studies and was not included as a predictor in the general empirical studies. Referencing *The Engineer of 2020*, this is consistent with an engineer needing strong analytical skills and having the ability to think analytically [3]. In addition, for engineering student retention, confidence in quantitative skills and attitudes about engineering were significant. Study Habits was a more dominant predictor for engineering retention studies than for general college education retention studies. On the other hand, Commitment to the Enrolled College and Family Support was a more dominant predictor for general college education retention studies than for engineering retention studies. Although the interest was in establishing a model for engineering student retention, those characteristics, that were only found to be significant in the general college education empirical studies, were included to establish a more complete model.

***Freshman Year Process:*** The freshman year process is based on Tinto's model that both academic and social integration must occur for a student to learn. Because of the significance of the Quantitative Skills variables such as the ACT Math and SAT Math, it may be hypothesized that for freshmen entering engineering college, academic integration is more important in the first term of engineering college than social integration. Because of the pace of the engineering curriculum, if a student does not do well academically in the first term, he/she is at risk for leaving Engineering due to being placed on academic probation and may lose confidence in his/her ability to do well academically. Ideally, social integration leads to more learning but it does not have a minimal threshold like academic integration. Consistent with Tinto's model, both academic and social integration are important concepts, but may vary significantly from student to student.

***Revising Career, Educational and College Goals:*** One of the pre-college characteristics is "commitment to career and educational goals". As the student takes courses in the first year, he/she re-evaluates his/her career and educational goals. This is consistent with both Tinto's model and Watson and Froyd's engineering education model of "interference" or interaction between the cognitive performance, career goals and self-identity [6], [12]. The block diagram (Figure 3) shows the student reaching a revised educational goal of either being interested in engineering as a major and career or in some other major, (usually in the science/math domain). Adelman's proposal of competing paths to a college major adds validity to this idea [5]. The student also re-evaluates whether he/she has commitment to the college he/she is enrolled in. If the student is doing well and has integrated both academically and socially, the student will continue with high probability at this college, even if he/she changes major. If the student has not integrated well, he/she may switch colleges or drop-out without transferring to another college.

***GPA influences decision to stay:*** Research supports that the first year college GPA influences a student's decision whether to stay in engineering. Elkins and Leutkemeyer reported that the average first year GPA for students who returned to engineering was significantly higher than for students who left engineering [27]. Burtner also found a significant difference in the GPA between the students who returned and left engineering after the first year [28]. Zhang et al. found that, within three semesters, most students with a low GPA had left engineering and concluded "We hypothesize the causal link that student self-efficacy improves with academic success and self-efficacy lead to improved retention" [26]. For students with a GPA less than 2.0, the engineering college typically places them on academic probation. As Zhang et al. found in their research, most of these students left engineering, either voluntarily or were pushed out" due to the requirements of academic probation.

In addition, Budny et al. found a strong correlation between the first semester GPA and persistence in engineering after six semesters [29]. French et al. found support for the college GPA influencing engineering retention after six to eight semesters [30]. Contrary to these studies, the Seymour and Hewitt study found no significant relationship between the GPA and retention [9].

Based on this research, the block diagram shows that both the GPA and the revised commitment to the goal of an engineering major and this particular college influence the final decision at the end of the first year of a freshman to either return or voluntarily leave. Based on this revised commitment, a student decides whether to return to engineering in the second year.

### D. Modeling from the Block Diagram

Based on the Block Diagram (Figure 3), two regression equation models can be developed, as described in this section.

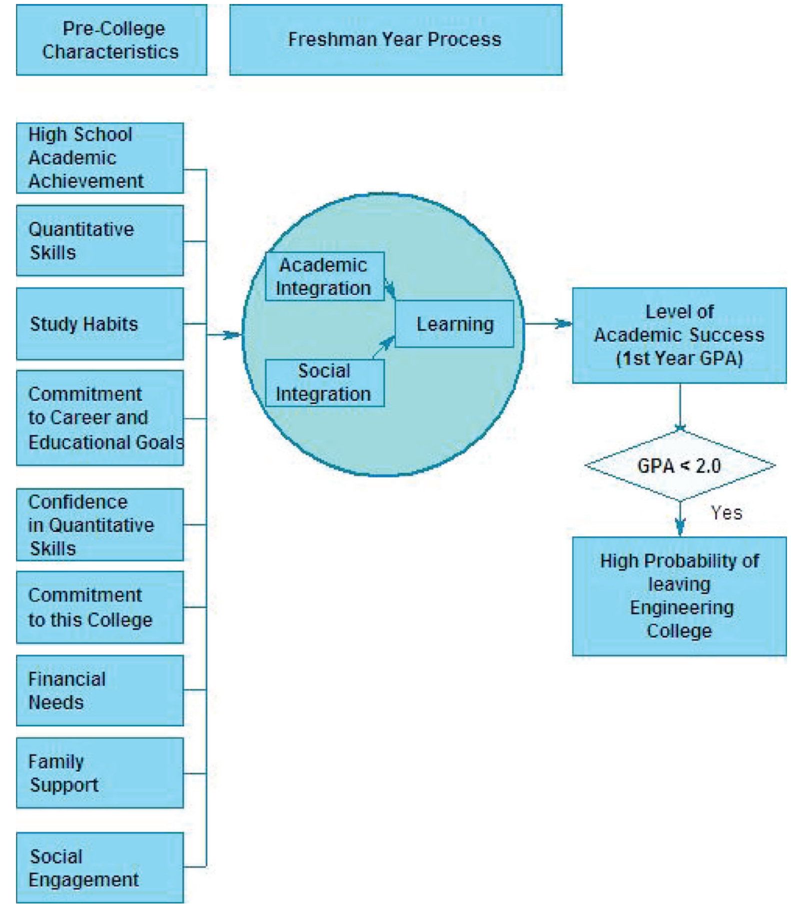


***Figure 4. Diagram for Freshman Student Academic Success (Regression Model).***

***Model for Academic Success (GPA):*** The first is the regression model for student academic success. The Freshman Year Process (the circle in Figure 3) can be viewed as a black box model with inputs being the Pre-College Characteristics and the output being the first year GPA. (See Figure 4)

Then from a modeling perspective, a regression model can be assumed with a linear relationship between the student academic success metric, first year GPA, and the Pre-College Characteristics.

$Y = f$ (Pre-College Characteristics: $X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9$)

Where:

$Y =$ First Year GPA

and the independent variables (X) represent the factors associated with the pre-college characteristics categories in Figure 3.

Let:

$X_1$ = High School Academic Achievement
$X_2$ = Quantitative Skills
$X_3$ = Study Habits
$X_4$ = Commitment to Career and Educational Goals
$X_5$ = Confidence in Quantitative Skills
$X_6$ = Commitment to Enrolled College
$X_7$ = Financial Needs
$X_8$ = Family Support
$X_9$ = Social Engagement

In practice, a set of variables would be selected for each pre-college characteristic category(X's) in Figure 4. Next, a factor analysis would be run on the variables in each pre-college category. Several factors may represent each category (X). The factors would then be entered in a linear regression with the dependent variable, the first year GPA. Interactions among the factors may be considered as appropriate in the regression modeling.

***Model for Retention:*** The second regression model (Figure 5) relates to student retention. The dependent variable is the retention decision portion of Figure 3; the student either stays in engineering or leaves after the first year (usually coded as a 0 or 1). In practice, an empirical analysis would use a logistic regression model. The regression model would include three independent variables: revised commitment to engineering, revised commitment to the university and the first year GPA. The first two variables would be based on a survey conducted at the end of the freshman year and the first year GPA would be the grade point average of all courses taken during the freshman year.

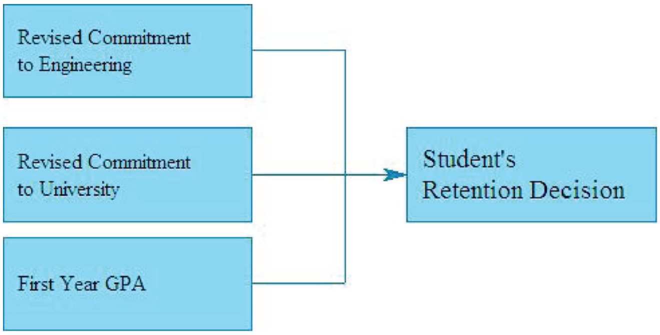


***Figure 5. Diagram for Retention Model (Logistic Model).***

## IV. RESULTS USING DATA FROM THE UNIVERSITY OF MICHIGAN

From the conceptual block diagram in Figure 3, Figures 4 and 5 were developed to enable an empirical analysis. From Figure 4, a regression model was applied to data from the 2004 and 2005 freshman classes at the University of Michigan. Data from the Cooperative Institutional Research Program (CIRP) survey and student academic data were included in a factor analysis, conducted for each pre-college characteristic category. From the nine pre-college characteristics categories, nineteen factors were generated. The factors, then, became the independent variables for the regression model for the student success (first year GPA) model. The result was a model for predicting the first year GPA of the first-time full-time entering engineering freshmen. The procedure and results of the student success (GPA) model with the pre-college characteristics are detailed in [31]. Table 4 summarizes the pre-college characteristics with significant factors ($p < .05$) for student success (GPA).

For the retention decision model (Figure 5) using a logistic regression, the GPA was considered as an independent variable with the retention decision as a dependent variable. Revised commitment to engineering and revised commitment to the university were not directly available as data. The GPA was not a significant predictor of freshman retention; freshman retention was consistently high (greater than 90%) across the range of a GPA greater than 1.5. It is hypothesized that the GPA was not significant because of the academic probation policies and student support activities available to freshmen. With a longer observed time of two years, Veenstra hypothesized that there would be a significant relationship between retention and GPA [32]. Support for this is found with Lee's research on persistence of engineering students at the University of Michigan [33]. She found that the first year grades influenced the third year engineering persistence.

| Pre-College Characteristic | Student Success Model |
|---|---|
| High School Academic Achievement | X |
| Quantitative Skills | X |
| Study Habits | |
| Commitment to Career and Educational Goals | X |
| Confidence in Quantitative Skills | X |
| Commitment to Enrolled College | |
| Financial Needs | |
| Family Support | |
| Social Engagement | |

***Table 4. Significant Predictors of first year GPA from the University of Michigan Data ($p < .05$).***

## V. SUMMARY AND CONCLUSIONS

W. Edwards Deming stated, “Without theory, experience has no meaning” [34]. Implied in this statement is that if a model does not exist, we cannot understand the underlying processes. Peter Senge also supports the need for a mental model or theory in order to lead and understand what can be accomplished [35].

The need for a model for freshman engineering retention is pressing for two reasons:

- A serious shortage of U.S. engineers in the workforce has led to a great concern about the ability of the U.S. to continue its leadership in science and technology innovation in the current global economy [36]. Therefore, there is an urgent need for more graduating engineers. Yet, the engineering colleges are challenged with retaining engineering students. Less than 57% of the students, who begin engineering college, complete their engineering program [37–38]. Of the students who leave engineering, approximately half of the students drop out after the first year. For this reason, this model on engineering student retention is focused on the first year of engineering college.
- A model does not currently exist that can be easily translated into statistical modeling.

In this paper, a model was developed with the primary focus on the significance of the pre-college characteristics affecting the first year GPA and retention to the second year (Figure 3). The freshman year is a year of transition and as such, the pre-college attitudes, experiences and goals help to shape the retention decision of whether a freshman decides to continue as an engineering major. This model satisfies the three requirements (stated in Section II. E) that Astin indicated was important for a model: simple to understand, encompass most empirical studies and can be easily used by researchers (with statistical modeling).

The literature review included in Tables A-1 and A-2 reiterates the importance that the effect of pre-college characteristics have on the success of a student and his/her retention and eventual graduation. The model suggested in this paper indicates that overall academic preparedness and quantitative skills developed in high school were important for success in the first year of engineering. In addition, scientific evidence exists that attitudes towards engineering and confidence in math, science and computers also contribute to student success in the first year of engineering college. We also found that a commitment to an engineering major in the freshman year is highly important.

Since there are more general empirical studies than engineering education empirical studies, it was interesting that the literature review showed differences in significant predictors of the GPA and retention between the two literature review sources. There were no cases where the ACT Math or SAT Math were significant for either the GPA or retention in the general education literature review but it was prevalent, that the SAT Math or ACT Math were significant for predicting the GPA for the engineering education literature. In addition, the variables that measure confidence in quantitative skills were significant for freshman engineering retention studies.

These facts, by themselves, support the need for an engineering education model separate from Tinto's or other educators' models. The proposed model of engineering student retention (Figure 3) is different from Tinto's model as follows:

- Quantitative skills is included as a pre-college characteristic based on the need for the engineering student to develop analytical skills.
- Attitudes about engineering and confidence in quantitative skills are considered important
- Consideration for a student leaving due to academic probation.

It has an advantage over other models in that a statistical model can be directly applied from the model (Figure 3). The general algorithm of assigning a set of questions to each category, developing a factor from a factor analysis and using regression analysis for statistical modeling can be applied. Depending on the survey used, the questions may be different from application to application.

The result of applying this model to University of Michigan data showed that High School Academic Achievement, Quantitative Skills, Commitment to Career and Education Goals and Confidence in Quantitative Skills predicted student success (GPA). The significance of these factors is consistent with the rationale concerning the differences between an engineering education and a general college education.

Using the University of Michigan data, this model shows promise. We strongly recommend that the framework of this model be considered for use by engineering colleges in their future research on freshman engineering retention.

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## AUTHORS

**Cindy P. Veenstra**, Ph.D. is principal consultant for Veenstra and Associates (Saline, MI). After a successful career as a process engineer, she returned to the University of Michigan to complete her Ph.D. in Industrial and Operations Engineering on modeling freshman engineering retention in 2008. She believes that we can use systems engineering concepts to engineer student success. Veenstra's research includes helping colleges design student success programs that graduate a high percent of engineering students. Her Ph.D. research included the development of the model for freshman engineering retention discussed in this paper. She is active in ASEE, ASQ, INFORMS and SME. She can be reached via email at cpveenst@umich.edu.

**Eric L. Dey**, Ph.D. is Associate Professor in the Center for the Study of Higher and Postsecondary Education at the University of Michigan School of Education. Dey's research is concerned with the ways that colleges and universities shape the experiences and lives of students and faculty. The central concern of this work is in identifying the influence that different institutional structures have on individuals, and the degree to which these influences are dependent on the evolving context within which the enterprise of higher education operates. As one example of this work, Dey was a member of the team of social scientists tapped to provide research on the educational effects of diverse student bodies; this work was foundational to the Supreme Court's decision supporting the continuing use of affirmative action in college admissions. He can be reached via email at dey@umich.edu.

**Gary D. Herrin**, Ph.D. is Professor of Industrial and Operations Engineering at the University of Michigan. He is a member of ASEE and IIE. He can be reached via email at gdherrin@umich.edu.

Address correspondence to:
Dr. Cindy P. Veenstra
Veenstra and Associates
P.O. Box 32
Saline, Michigan 48176
email: cpveenst@umich.edu

## APPENDIX

### Description of Table A-1 and Table A-2

To obtain a better definition of the pre-college characteristics important for a model of engineering student retention, a literature review of a cross-section of empirical studies related to student retention was conducted. For a model to work well, a necessary condition is that it should accommodate current significant empirical studies. For example, if an empirical study indicates that strong quantitative skills from high school are important, the model should also have an element that includes pre-college quantitative skills.

This literature review was conducted to support a model of freshman engineering student retention. Because few empirical studies of freshman engineering student retention were found, the initial literature review included both empirical studies related to freshman and sophomore retention. In addition, to provide more evidence for the model, a literature review that summarized a longitudinal approach of 3 to 6 year retention (or graduation) was conducted. As a result, the following two tables were developed and are included as attachments.

Table A-1 lists the empirical studies that are related to first year and second year student success (as measured by the college GPA) and first year and second year retention, as measured by whether a student returned to the engineering college for the 2nd year.

Table A-2 lists the empirical studies that are related to 3rd year through 6th year student success (as measured by the college GPA) and 3rd through 6th year retention or graduation.

In both the Tables A-1 and A-2 attachments, empirical research articles specific to engineering are listed as engineering education source (columns 2 and 3). Articles on empirical research of general college studies are listed as general college source (columns 4 and 5). In selecting research literature to review, the following research strategy was used. Both multi-institutional and single-institutional research was used. Empirical studies addressing the following retention subjects with pre-college characteristics as predictors were reviewed:

a. 1st year student success (college GPA)
b. first year through 2nd year retention
c. student success for 3rd year through graduation (cumulative college GPA)
d. 3rd year retention through graduation (retention or graduation rate)

Specific to engineering education retention research, the following sources were reviewed:

1. For the past ten years (1997 to present), articles in the ASEE Journal of Engineering Education (JEE) and the ASEE Conference Proceedings.
2. For the past three years, articles in the Conference Proceedings of the Frontiers in Education Conference.

3. For the Besterfield-Sacre et al. JEE articles (1997 and 1998), review of articles listed in the bibliography.
4. Significant to engineering student retention, include the UCLA/ Higher Education Research Institute (HERI) longitudinal study under the direction of Alexander and Helen Astin with HERI researchers (Astin and Astin, 1992), that specifically looked at engineering students. Also include relevant articles on engineering student retention published by HERI researchers.
5. The Seymour and Hewitt research in *Talking about Leaving (1997)*, and the Daempfle (2003) research.

Specific to general student retention research, the following sources were reviewed:

1. College studies included in Braxton's study of Tinto's model (Braxton, 2000, Tables 7 and 8, pp. 20–22)
2. Tinto (1993, 2006)
3. ACT articles related to college student retention, including a summary of a meta-analysis study of 109 studies (Lotkowski et al. 2004). The details of the meta-analysis are in Robbins et al. (2004)
4. Selected UCLA/HERI studies related to college student retention
5. Selected articles from *Journal of College Student Retention* and Allen (1999)

| Characteristic | Engineering Education 1st or 2nd Year Success (GPA) | Engineering Education 1st or 2nd Year Retention | General College Education 1st or 2nd Year Success (GPA) | General College Education 1st or 2nd Year Retention |
|---|---|---|---|---|
| **High School Academic Achievement** | | | | |
| High School GPA | Levin & Wyckoff (1988)<br>Lackey et al. (2003)<br>Veenstra et al. (2008) | Levin & Wyckoff (1988)<br>Burtner (2004) | | Glynn et al. (2005) |
| High School Rank | Besterfield-Sacre et al. (1997)<br>Veenstra et al. (2008) | Besterfield-Sacre et al. (1997)<br>Scalise et al. (2000) | Allen (1999) | Terenzini et al. (1985)<br>Brower (1992)<br>Allen (1999) |
| SAT Total | | Scalise et al. (2000) | | Terenzini et al. (1985)<br>Tinto (1993) |
| ACT Composite | | | | Wohlegemuth et al. (2006) |
| Academic-related skills (other than SAT or ACT) | | | | Donovan (1984)<br>Terenzini et al. (1985) |
| Communication skills | | Besterfield-Sacre et al. (1997) | | |
| **Quantitative Skills** | | | | |
| SAT Math | Levin & Wyckoff (1988)<br>Besterfield-Sacre et al. (1997)<br>Lackey et al. (2003) | Elkins & Luetkemeyer (1974)<br>Besterfield-Sacre et al. (1997) | | |
| ACT Math | | Leuwerke et al. (2004) | | |
| Math or science preparation | Levin & Wyckoff (1988)<br>Budny et al. (1998)<br>Besterfield-Sacre et al. (2002)<br>Veenstra et al. (2008) | Budny et al. (1998) | | |
| **Study Habits** | | | | |
| Good study habits | Levin & Wyckoff (1988)<br>Besterfield-Sacre et al. (1997)<br>Bernold et al. (2007) | Scalise et al. (2000) | | Donovan (1984)<br>Glynn et al. (2005) |
| Came late to class | Shuman et al. (2003) | | | |
| Overwhelmed | Shuman et al. (2003) | | | |
| Learning preferences | Bernold et al. (2007) | | | |
| **Commitment to Career and Educational Goals** | | | | |
| Career and educational goals | Veenstra et al. (2008) | Elkins & Luetkemeyer (1974) | | Pascarella & Terenzini (1980)<br>Pascarella & Chapman (1983)<br>Donovan (1984)<br>Terenzini (1985)<br>Pascarella et al. (1986)<br>Tinto (1993)<br>Glynn et al. (2005) |
| Drive to achieve/ motivation | | Elkins & Luetkemeyer (1974) | | Allen (1999) |

*(Continues...)*

***Table A-1. 1st year and 2nd year Student Success and Retention Empirical Studies.***

| Characteristic | Engineering Education 1st or 2nd Year Success (GPA) | Engineering Education 1st or 2nd Year Retention | General College Education 1st or 2nd Year Success (GPA) | General College Education 1st or 2nd Year Retention |
|---|---|---|---|---|
| **Commitment to Career and Educational Goals** | | | | |
| Like engineering | | Besterfield-Sacre et al. (1997) | | |
| Good impression of engineering | | Levin & Wyckoff (1988)<br>Besterfield-Sacre et al. (1997) | | |
| **Confidence in Quantitative Skills** | | | | |
| Confidence in basic engineering skills (calculus, physics and computer skills) | Veenstra et al. (2008) | Besterfield-Sacre et al. (1997) | | |
| Enjoy math and science | Besterfield-Sacre et al. (1997) | Besterfield-Sacre et al. (1997) | | |
| **Commitment to Enrolled College** | | | | |
| Commitment to enrolled college | | | | Pascarella and Terenzini (1980)<br>Pascarella (1985)<br>Terenzini (1985)<br>Pascarella et al. (1986)<br>Mallette & Cabrera (1991)<br>Brower (1992)<br>Glynn et al. (2005) |
| **Financial Needs** | | | | |
| Financial needs (savings, scholarship or working) | Besterfield-Sacre et al. (1997) | | Allen (1999) | Cabrera et al. (1990)<br>Allen (1999)<br>Glynn et al. (2005)<br>Wohlegemuth et al. (2006) |
| **Family Support** | | | | |
| Years of parent(s)' education | | | Allen (1999) | Donovan (1984)<br>Terenzini et al. (1985)<br>Allen (1999)<br>Glynn et al. (2005) |
| Income level of parents | | | | Donovan (1984)<br>Cabrera et al. (1990) |
| **Social Engagement** | | | | |
| Social involvement | | | | Astin (1984) |
| Social personality | | Brown & Cross, Jr. (1993) | | |

***Table A-1. (Continued … )***

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| Characteristic | Engineering Education 3–6 years Success (GPA) | Engineering Education Retention/ Graduation | General College Education 3–6 years Success (GPA) | General College Education Retention/ Graduation |
|---|---|---|---|---|
| **High School Academic Achievement** | | | | |
| High School GPA | | Astin & Astin (1992)<br>Burtner (2004)<br>Zhang et al. (2004)<br>Mendez et al. (2008) | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Munro (1981)<br>Getzlaf et al. (1984)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004)<br>Astin & Oseguera (2005) |
| High School Rank | Besterfield-Sacre et al. (2002)<br>French et al. (2005) | Moller-Wong & Eide (1997)<br>French et al. (2005) | | Wohlegemuth et al. (2006) |
| SAT Total | Padilla et al. (2005) | | | Tinto (1993)<br>Astin & Oseguera (2005) |
| SAT Verbal | French et al. (2005) | Mendez et al. (2008) | | |
| ACT Composite | | | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Lotkowski et al. (2004)<br>Robbins et al. (2004)<br>Wohlegemuth et al. (2006) |
| Academic-related Skills (other than SAT or ACT) | | | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Munro (1981)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004) |
| Math Entry Level | | Alting & Walser (2006) | | |
| Academic Self-Confidence | | | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Pascarella (1985)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004) |
| **Quantitative Skills** | | | | |
| SAT Math | Besterfield-Sacre et al. (2002)<br>French et al. (2005) | Astin &Astin (1992)<br>Zhang et al. (2004)<br>French et al. (2005)<br>Mendez et al. (2008) | | |
| ACT Math | | Moller-Wong & Eide (1997) | | |
| Math or science preparation | | Seymour & Hewitt (1997)<br>Seymour (2001)<br>Johnson & Sheppard (2002)<br>Hartman & Hartman (2006) | | |
| High School years of math | | | | Getzlaf et al. (1984)<br>Adelman (1999)<br>Astin & Oseguera (2005) |
| **Study Habits** | | | | |
| Good study habits | | Brainard & Carlin (1998)<br>Daempfle (2003) | | Tinto (1993) |
| Learning preferences | Bernold et al. (2007) | Bernold et al. (2007) | | |
| Hours studying/ doing homework in high school | | Astin & Astin (1992) | | Astin & Oseguera (2005) |

*(Continues…)*

***Table A-2. 3rd through 6th year Student Success and Retention/Graduation Empirical Studies.***

| Characteristic | Engineering Education 3–6 years Success (GPA) | Engineering Education Retention/ Graduation | General College Education 3–6 years Success (GPA) | General College Education Retention/ Graduation |
|---|---|---|---|---|
| **Study Habits (continued)** | | | | |
| Came late to class | | | | Astin & Oseguera (2005) |
| **Commitment to Career and Educational Goals** | | | | |
| Career and educational goals | | Astin & Astin (1992) | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Pascarella (1985)<br>Tinto (1993)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004)<br>Astin & Oseguera (2005) |
| Drive to achieve/ motivation | | French et al. (2005) | Lotkowski e t al. (2004)<br>Robbins et al. (2004) | Astin & Oseguera (2005) |
| Good impression of engineering | | Hartman & Hartman (2006) | | |
| Father is an engineer | | Astin & Astin (1992) | | |
| Started as freshman in engineering | | Astin & Astin (1992)<br>Johnson & Sheppard (2002) | | |
| High score on status striving | | Astin & Astin (1992) | | |
| **Confidence in Quantitative Skills** | | | | |
| Confidence in calculus, physics, and computer skills | | Brainard & Carlin (1998) | | |
| Enjoy math and science | | Brainard & Carlin (1998) | | |
| High self-rating in math | | Astin & Astin (1992) | | |
| Strong scientific Orientation | | Astin & Astin (1992)<br>Moller-Wong & Eide (1997) | | |
| **Commitment to Enrolled College** | | | | |
| Commitment to enrolled college | | | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Getzlaf et al. (1984)<br>Pascarella (1985)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004) |
| **Financial Needs** | | | | |
| Financial needs (savings, scholarships or working) | | Astin & Astin (1992)<br>Brainard & Carlin (1998)<br>Johnson & Sheppard (2002) | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Tinto (1993)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004)<br>Astin & Oseguera (2005)<br>Wohlegemuth et al. (2006) |
| **Family Support** | | | | |
| Years of parent(s)' education | | | | Pascarella (1985)<br>Astin & Oseguera (2005) |

*(Continues…)*

***Table A-2. (Continued … )***

| Characteristic | Engineering Education 3–6 years Success (GPA) | Engineering Education Retention/ Graduation | General College Education 3–6 years Success (GPA) | General College Education Retention/ Graduation |
|---|---|---|---|---|
| **Family Support** | | | | |
| Income level of parents | | Johnson & Sheppard (2002) | | Pascarella (1985)<br>Tinto (2006–2007) who references NCES (2003.p.57, Table 2.0C) |
| Social-economic status | | Brainard & Carlin (1998)<br>Johnson & Sheppard (2002) | Lotkowski et al. (2004)<br>Robbins et al. (2004) | Munro (1981)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004) |
| **Social Engagement** | | | | |
| Social involvement | | | | Astin (1984)<br>Lotkowski et al. (2004)<br>Robbins et al. (2004) |

***Table A-2. (Continued … )***

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