The Aptitudes of Engineering Students

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ABSTRACT

This report presents the results of a validation study of 256 University of Texas-Austin (UT-Austin) engineering students. The engineering students were administered the Johnson O'Connor Research Foundation's standard battery of aptitude and knowledge tests to examine how aptitude performance relates to performance in and completion of the engineering major.

The engineering students as a whole were a quite able group. They averaged High scores (70^{th} percentile or above) on Graphoria, Foresight, Number Series, Memory for Design, Number Memory, and Mathematics Vocabulary. Also, students who successfully completed an engineering degree at UT-Austin scored significantly higher than unsuccessful students on Analytical Reasoning, Number Series, Number Facility, Incomplete Open Cubes (a test of structural visualization), and both English and Mathematics Vocabulary. In terms of engineering degree specialties, mechanical engineering majors excelled on Inductive Reasoning, Incomplete Open Cubes, and Spatial Visualization. Electrical and chemical engineering majors excelled on the two vocabulary tests. Correlations between standard battery performance and college grade point averages showed significant relationships for Foresight, Number Facility, Memory for Design, and the two vocabulary tests.

A follow-up questionnaire was sent to participants in the study, but there were too few respondents to obtain meaningful results.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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From the Foundation, Ms. Marsha Buckner, test administrator from our Seattle office, worked with Mr. Halton in the planning for the study and organized the recruitment and testing of the first two cohorts of students. Mr. David Lyon, director of our Los Angeles testing office, took over leadership for the latter two years of recruitment and testing. Other Foundation staff who tested students included Mr. Russell Burke, test administrator from our Washington, D.C., office; Mr. Richard Hoffman, director of our Houston office; Mr. Edwin Delaney, test administrator from our New York office; and Ms. Karen Metzger and Mr. Don Anderson, test administrators from our Chicago office. Ms. Wendy Bigelow, Director of Testing for the Foundation, assisted greatly with the organization and recruitment for the study. Two research assistants, Ms. Mikako Nakajima and Ms. Lia Meyer, worked on the analysis of the overall aptitude pattern of the 256 undergraduate majors. Finally, Mr. Russell Burke and Mr. David Ransom offered very constructive criticism and useful suggestions throughout the writing of this report.

INTRODUCTION

A long-term study of engineering students was proposed by David Schroeder and Marsha Buckner at the Johnson O'Connor Research Foundation (henceforth referred to as "the Foundation") in 1992 (Schroeder & Buckner, 1992). The purpose of the study was to relate the test scores of engineering students to their performance in engineering school.

Regarding the results of engineering students, it was deemed important to examine the relationships of aptitude performance to performance in the engineering major, including grade point averages. In addition, we examined the aptitude performance of: a) engineering students who successfully completed their education in engineering as compared to students who did not, and b) students within various engineering majors.

From 1992 to 1995 we recruited incoming freshmen who were enrolled in the School of Engineering at the University of Texas-Austin (UT-Austin) to take our standard battery of tests. We subsequently collected additional information from the engineering students, including their college records.

Previous Research

Before describing the current study in this report, it is important to discuss the previous research in engineering and spatial aptitudes that has been conducted within the Foundation and outside of the Foundation to place the research findings in this study into a broader context.

Stevens Institute of Technology. The earliest reported research on engineering students within the Foundation was conducted at the Stevens Institute of Technology (SIT) in the 1930s (Technical Report 97, Volumes I & II). Freshmen and senior engineering students at SIT were administered the Foundation's standard battery of tests from 1929 to 1932. The students were subsequently followed up in 1941 regarding their engineering careers. The results are quite interesting. For instance, students who were tested as freshmen and successfully graduated with a degree in engineering tended to score high on Structural Visualization, to be Subjective, and to score low on English Vocabulary and Tonal Memory. Conversely, students who were tested as freshmen and did not graduate in engineering tended to score low on Structural Visualization and Number Memory and to be Objective.

Freshmen in the SIT study were also divided into those who had good scholarship, or grades, and those who had poor scholarship. Those who had good scholarship scored very high on Structural Visualization, low on English Vocabulary, and were more Subjective. Those with poor scholarship scored roughly average on Structural Visualization and low on English Vocabulary and Tonal Memory.

As with freshmen-tested graduates, senior-tested graduates of the SIT also scored quite high on Structural Visualization, high on Accounting Aptitude (Graphoria), and low on Tonal Memory. Finally, seniors with good scholarship scored quite high on Structural Visualization and Accounting Aptitude but scored average on English Vocabulary, low on Tonal Memory, and tended to be Subjective.

Princeton University. Another study of engineering students was conducted by the Foundation in 1960 at Princeton University (Technical Report 654). The sample was rather small: 21 engineering students and 4 students who transferred out of engineering school. The students who remained in the program tended to score high on Accounting Aptitude (Graphoria), Memory for Design, Number Reasoning (Number Facility), Wiggly Block, Ideaphoria, Analytical Reasoning, Silograms, Foresight, and English Vocabulary.

Other Foundation studies. The Foundation has conducted a number of additional studies of engineering. In 1947 Licht found that 29 steel company engineers scored significantly higher on the Wiggly Block test than the general male Foundation testing population and higher than company employees who were not engineers (Validation Bulletin 74). In 1972 Brown analyzed the test scores of 138 Foundation examinees who identified themselves as engineers on a follow-up questionnaire (Technical Report 762). Again, the engineers scored significantly higher than male Foundation examinees on Wiggly Block, along with Structural Visualization, Memory for Design, Analytical Reasoning, and Tweezer Dexterity.

In the *Wiggly Block Worksample 3,4,5,6,7 Manual* (1978), Daniel summarized our findings on Wiggly Block and engineering as follows: a) engineers and engineering students tend to score very high; b) engineers who work in management or sales tend to score not as high as technical or development engineers; c) to date we have not been able to identify score differences among branches of engineering; and d) test scores predict salary in engineering and grades in college engineering courses.

*O*NET*. The O*NET is maintained by the U.S. Department of Labor and is a successor to the 60-year-old Dictionary of Occupational Titles (DOT). The O*NET provides information concerning skills and knowledge that are needed for given occupations as well as labor market information on employment levels and occupational outlook. The O*NET reports that the abilities shown below are needed for the engineering specialties we examined in the current study (U.S. Department of Labor, n.d.). In addition to the O*NET abilities listed below, in parentheses we list the Foundation aptitude that most closely matches the given ability where appropriate.

- Mechanical Engineering – information ordering (Analytical Reasoning), mathematical reasoning, deductive reasoning, written comprehension, near vision, problem sensitivity, inductive reasoning (Inductive Reasoning), oral comprehension, categorical flexibility, number facility (Number Facility).
- Electrical Engineering – problem sensitivity, deductive reasoning, oral comprehension, oral expression, written comprehension, inductive reasoning (Inductive Reasoning), information ordering (Analytical Reasoning), written expression, category flexibility, near vision.
- Chemical Engineering – information ordering (Analytical Reasoning), mathematical reasoning, problem sensitivity, category flexibility, deductive reasoning, inductive reasoning (Inductive Reasoning), oral comprehension, written comprehension, number facility (Number Facility), fluency of ideas (Ideaphoria).
- Civil Engineering - problem sensitivity, deductive reasoning, oral comprehension, oral expression, mathematical reasoning, written comprehension, inductive reasoning (Inductive Reasoning), information ordering (Analytical Reasoning), near vision, visualization (Structural Visualization).
- Aeronautical Engineering – critical thinking, reading comprehension, active listening, complex problem solving, operations analysis, speaking, mathematics, science, writing, monitoring.
- Petroleum Engineering – written comprehension, oral comprehension, oral expression, inductive reasoning (Inductive Reasoning), problem sensitivity, written expression, information ordering (Analytical Reasoning), deductive reasoning, speech clarity, speech recognition.

Conclusions from previous studies. While many of the Foundation studies are old and contain small sample sizes (apart from the SIT study), we can draw a number of conclusions. First, those who graduated in engineering and had good scholarship tended to score high on Structural Visualization, and Wiggly Block in particular. Second, engineers tended to be Subjective. Finally, the O*NET indicates that reasoning (Inductive and Analytical) and Number Facility are related to engineering.

Advantages of current study. The current study has a number of advantages over the previous studies of engineering students and engineers. First, the sample of engineering students in this study is much larger than many of the previous studies, which allows for more solid conclusions to be drawn. Second, the current study uses much more contemporary data than previous studies. For instance, both the engineering major and work in the field of engineering have likely changed since the original SIT study in the 1930s and the Princeton University study in 1960. Finally, this study has a richer set of data than some of the previous studies in terms of choice of engineering specialty and in terms of various grade-point averages (GPAs) at UT-Austin, both the overall GPA and the GPA for various sets of technical courses.

Engineering Areas of Inquiry

As noted, in this study we will relate aptitude test scores to the experience of undergraduate engineering students at UT-Austin. We will examine the aptitude performance of:

1. Engineering majors overall;
2. Successful as compared to unsuccessful engineering majors, i.e., those who completed or did not complete a degree in engineering; and
3. Engineering majors by degree specialty (e.g., chemical, mechanical).

In addition, we will study the relationships between aptitude scores and academic performance in terms of various college grade point averages (see Appendix A for information on the calculation of the grade point averages).

METHOD

Examinees

The examinees for this study began as students entering the School of Engineering at UT-Austin between 1992 and 1995. The School of Engineering is a moderately selective engineering school that admits about 1,500 students each year relative to an applicant pool of roughly 2,100. About 1,000 of those admitted actually enroll. To be admitted, students must generally score 1100 (SAT-Verbal + SAT-Quantitative) on the Scholastic Assessment Test (SAT) and rank in the top 25% of their high-school graduating class. In addition, admission decisions are influenced by such factors as unit requirements, degree plan desired, and geographical location, among others.

From the 1,000 first-time-in-college students enrolled in the School, each year we recruited about 60 to 80 students to participate in this study. The recruitment procedures were as follows: In late August of each year, we mailed recruitment letters to students in that year's entering class who attended summer orientation sessions. We asked students to respond by mail concerning their willingness to participate. For each student who agreed to participate, we arranged testing appointments that suited their schedule during the two weeks our test administrators were on the UT-Austin campus. Among the students who did not respond to the mail solicitation, we nonsystematically[1] selected a portion of them to be contacted by phone. For those who in this way agreed to participate in the study, we scheduled testing appointments. Of the full sample who participated in the study, roughly equal proportions were recruited by mail and by phone.

From 1992 to 1995 we tested a total of 256 UT-Austin School of Engineering freshmen on the Foundation's standard battery. Of the sample, 56 (21.9%) were tested in 1992, 54 (21.1%) in 1993, 80 (31.3%) in 1994, and 66 (25.8%) in 1995. The students ranged in age from 16 to 23, and slightly more than 77% were 18 years old (M = 18.05, SD = 0.75). Of the 256 students, 169 (66.0%) were male, and 87 (34.0%) were female. The proportion of males to females was quite similar across age and year of testing.

Measures and Procedures

Foundation standard test battery. Before being tested, all students gave informed written consent to be tested by us. The consent agreement also granted us permission to use their university records including high school and college transcripts and college-entrance exam scores. The engineering students took the Foundation's standard battery of tests in the final two weeks of the first month of classes. The tests were administered by full-time, trained Foundation test administrators. The students were administered 19 aptitude tests, two tests of knowledge (English and Mathematics Vocabulary), and two additional tests (Writing Speed and Eye & Hand).

Roughly one-half of the aptitude tests were administered individually by trained test administrators, while the other tests were taken in group settings with the use of a slide projector and headphones to present the instructions. Table 1 provides the reliabilities and brief descriptions of the aptitude traits measured by the tests. Wiggly Block and Paper Folding are combined in our standard testing battery to create the

[1]Although our selections here were not literally random, each nonresponding student had more-or-less the same chance of being selected--that is, our selections were like random selections.

Structural Visualization score that we present to our testing clients. Paper Folding was not included in this study, though. Therefore, a Spatial Visualization score was derived from scores on Wiggly Block and Incomplete Open Cubes (IOC), which is another test of spatial ability. [2] The IOC test has two scales: only the first, analog-processing, was used in this study. For more information on IOC, see Technical Report 1988-5.

Among the other tests we administered, two tests measured reasoning aptitudes (Inductive and Analytical Reasoning), two measured numerical aptitudes (Number Series and Number Facility), and two measured dexterity (Finger Dexterity and Tweezer Dexterity). Three tests measured types of musical abilities (Tonal Memory, Pitch Discrimination, and Rhythm Memory), and four tests measured memory abilities (Memory for Design, Silograms, Number Memory, and Observation). Finally, Graphoria is a perceptual speed measure, Color Perception measures whether someone has deficiencies in color vision, Word Association measures whether someone has an Objective or Subjective personality, Ideaphoria measures idea-production ability, and Foresight measures the ability to think of many possibilities. As can be seen from Table 1, most of the tests show reliabilities greater than .80, which is often viewed as a lower bound of acceptable reliability for testing purposes (Nunnally, 1978). The tests have also shown adequate validity, as documented in various Foundation reports published over the years (e.g., Statistical Bulletin 2004-6; Technical Report 1982-6).

Follow-up questionnaire. In 2005 (approximately 10 years after the standard-battery testing), we sought to reach out to our sample to learn more about their experience since finishing college. To that end, we sent a follow-up questionnaire to the 123 participants who had graduated from the UT-Austin's engineering program. We received completed questionnaires for 50 participants who were still working in engineering, engineering management, or a technical field and 8 participants who had left technical work. We judged that this sample size was not sufficient to permit appropriate statistical tests, and so we will not present findings from those data.

Analyses

Aptitude test scores. The raw test scores on each aptitude test were used to perform the analyses in this report. A caveat to the use of raw scores should be mentioned, though. Because performance on the tests differs with age, it was important to partial, or remove the influence of, age from the raw test scores before performing the analyses. To remove the influence of age on the raw test scores, a regression was

[2] "Spatial Visualization" will be used to represent the combination of Wiggly Block and Incomplete Open Cubes. The term "Structural Visualization" will be reserved for use only when combining Wiggly Block and Paper Folding.

conducted in which age, age-squared, and age-cubed were used to predict each test score. Then, the unstandardized residuals were saved and added to the overall mean on each test to yield the raw test scores partialled for age. Because most of the examinees were 18 or near-18 at the time of testing, the effect of the age-partialling was fairly modest.

College performance. We also derived grade point averages (GPAs) for various subject areas in which engineering students took classes, which we then correlated with the standard battery tests. We calculated 11 GPAs: American Government, History, English, Mathematics, Physics, Science/Mathematics, Humanities, Basic Sequence, Major Sequence,[3] Engineering, and Overall. We chose these subject areas because they were common to all engineering majors. See Appendix A for a complete description of how the GPAs were calculated.

RESULTS

Before we examined the test results, it was important to address whether our sample was representative of the freshmen in the School of Engineering at UT-Austin as a whole. In Statistical Bulletin 1998-1, Schroeder, Nakajima, and Meyer showed that the engineering students in this study slightly surpassed freshmen in the School of Engineering as a whole with regard to high school rank and SAT Quantitative and Verbal scores, but the differences were small in terms of the overall distributions. Thus, our sample is reasonably representative of the students in UT-Austin's School of Engineering.

Aptitude Scores for Engineering Students Overall and for Successful and Unsuccessful Students

Table 2 shows descriptive statistics for aptitude test scores for three groups of engineering students: a) the overall sample, b) those who successfully obtained an engineering degree at UT-Austin ("successful"), and c) those who did not obtain a degree ("unsuccessful").[4] The test scores were first partialled for age so that any differences between the latter two groups on age would not affect the results. The scores for the students overall, while interesting, are not the focus of the analysis, as it is important to understand the aptitudes that separate successful from unsuccessful

[3] Basic Sequence courses are engineering courses typically taken in the first two years of undergraduate schooling, while Major Sequence courses are higher level engineering courses.

[4] Many of the "unsuccessful" students here were probably "successful" in terms of other (non-engineering) programs at UT-Austin, programs at other institutions, and/or other endeavors in their lives. Our point here is only that they did not complete the engineering program at UT-Austin.

students. Nevertheless, Table 2 shows that engineering students as a whole score High (70^{th} percentile or above) on a number of aptitudes, including Graphoria (mean percentile = 77.60), Foresight (72.34), Number Series (77.60), Memory for Design (76.93), Number Memory (70.49), and Mathematics Vocabulary (88.77). Contrary to expectation, the sample as a whole did not score high on Wiggly Block, with a mean percentile of 58.86.[5]

In terms of the differences between successful and unsuccessful students, independent-samples *t*-tests showed that the successful students scored significantly higher than the unsuccessful students on Analytical Reasoning, $t(252) = 2.21$, $p = .03$; Number Series, $t(252) = 2.54$, $p = .01$; Number Facility, $t(252) = 2.30$, $p = .02$; Incomplete Open Cubes, $t(179) = 3.39$, $p = .047$; Tonal Memory, $t(250) = 1.98$, $p < .05$; Number Memory, $t(252) = 2.76$, $p = .01$; English Vocabulary, $t(244) = 2.24$, $p = .03$; and Mathematics Vocabulary, $t(249) = 3.49$, $p = .001$.

In Figure 1 we show how scores on Analytical Reasoning (AR) relate to success in engineering school. We chose to present results for AR because Technical Reports 654 and 762, as well as the O*NET research, show the relationship between AR and engineering. As can be seen, among students scoring high on Analytical Reasoning, a substantially higher percentage completed the engineering program as compared to students scoring average or low on Analytical Reasoning. The high-AR students had about a 58% chance of completing their degrees at the UT-Austin engineering school, compared to the 38% and 35% chances for average-AR and low-AR students, respectively, completing their degrees at UT-Austin in engineering.

In addition to examination of significance tests, it is also interesting to look at the effect sizes of the differences between the means for successful and unsuccessful students, as shown in Figure 2. Effect sizes are not a function of sample size, so they provide a clear picture of the magnitude of mean differences. Using Cohen's *d* (Cohen, 1988) as our measure of effect size, the following effect sizes are related to statistically significant differences on the *t*-tests in favor of successful students: Number Memory ($d = .31$), Incomplete Open Cubes (.30), English Vocabulary (.29), Mathematics Vocabulary (.28), Analytical Reasoning (.27), Number Facility (.24), Number Series (.23), and Tonal Memory (.23).

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[5] For Incomplete Open Cubes, we could not compare the sample with the general Foundation population because we had not constructed norms for the general Foundation population. (Similarly, we could not make the analogous comparison for Spatial Visualization.)

Engineering Degree Specialty

Table 3 shows how students with various engineering degree specialties (i.e., Electrical, Mechanical, Chemical, and Other[6]) scored on the test battery, including both graduates and non-graduates within these specialties. The omnibus analysis of variance test that we conducted for each test shows whether there are differences among the four degree specialty categories that we created, but does not indicate specifically where those differences lie. The results are quite interesting, in that there were significant differences among the four categories on the following tests: Inductive Reasoning, $F(3, 119) = 3.18$, $p = .03$; Incomplete Open Cubes, $F(3, 97) = 5.33$, $p < .01$; Spatial Visualization, $F(3, 97) = 3.87$, $p = .01$; Silograms, $F(3, 119) = 2.70$, $p < .05$; English Vocabulary, $F(3, 115) = 5.79$, $p < .001$; and Mathematics Vocabulary, $F(3, 117) = 4.72$, $p < .01$.

On Inductive Reasoning, the engineering degree specialties of Mechanical and Other tended to excel, while Chemical and Electrical engineering majors tended to score lower. For Incomplete Open Cubes, Mechanical scored the highest, followed closely by Electrical, and then Chemical, with Other clearly lower than the other three degree specialties. For Spatial Visualization, a similar pattern held, with Mechanical scoring highest, followed by Electrical and Chemical, which scored similarly, and then Other, which is clearly lower than the other three degree specialties. Silograms showed a slightly different pattern: students with Mechanical and Electrical engineering majors tended to excel, while the other majors did not score as high. The pattern for the two vocabulary tests is also different, as Electrical and Chemical excel.

College Academic Performance

Table 4 shows the correlations between standard battery performance and college grade point averages for the engineering students. Foresight has statistically significant positive correlations with the Mathematics (.26), Physics (.20), Science/ Mathematics (.26), Humanities (.44), Basic Sequence (.33), Major Sequence (.32), Engineering (.36), and Overall (.18) GPAs. Although these correlations are statistically significant, they are in the low to moderate range. Number Facility also has statistically significant positive correlations with the Basic Sequence (.22), Major Sequence (.20), and Engineering (.22) GPAs. Another standard battery test that is significantly correlated with a number of GPAs is Memory for Design, which has positive correlations with the Mathematics (.16), Physics (.23), Science/Mathematics (.23), Basic Sequence (.30), Major

[6] The Civil, Aeronautical, Petroleum, and Architectural degree specialties were too small to analyze as separate groups, and so we combined them into this "Other" category.

Sequence (.19), and Engineering (.26) GPAs. It should also be noted that performance on both English and Mathematics Vocabulary is positively related to all 11 GPAs.

With respect to the spatial aptitude, the only GPAs with which performance on Wiggly Block had significant positive relationships were the Physics (.16) and Basic Sequence (.22) GPAs. Incomplete Open Cubes was not significantly related to any GPAs apart from American Government (.26). Spatial Visualization was positively related to Physics (.19), and Basic Sequence (.27).

Figure 3 shows the grade-point averages in engineering courses (Major and Basic Sequence) for examinees who score High on Analytical Reasoning, Number Facility, and Memory for Design as compared to examinees who score Low/Average on these three tests, respectively. These tests were chosen for display because they showed significant correlations with Engineering GPA. As can be seen from the figure, there are sizable differences in grade point averages in engineering courses between students who score High and Low/Average on the three tests.

DISCUSSION

It is clear that engineering majors as a group, including both students who successfully completed the engineering program and those who did not, are quite able. For instance, the overall group of engineering students averaged High scores (70th percentile or above) on six Foundation tests: Graphoria, Foresight, Number Series, Memory for Design, Number Memory, and Mathematics Vocabulary. The fact that engineering majors overall averaged High scores on one numerical aptitude (Number Series) and a spatial-related aptitude (Memory for Design) is logical. The results also indicate that engineering majors excel on perceptual speed and have foresight. It is also interesting to note that engineering majors at UT-Austin as a whole did not average High scores on Wiggly Block. Their average score on Wiggly Block is near the 59th percentile.[7]

Successful and unsuccessful students. With regard to the structural visualization measures, the students who graduated in engineering scored significantly higher than those who did not complete the program on Incomplete Open Cubes, but the differences on Wiggly Block and Spatial Visualization were not significant. The

[7] As noted earlier, structural visualization was measured in this study with Incomplete Open Cubes (IOC) rather than Paper Folding, in conjunction with Wiggly Block. We could not compare the engineering students with the general Foundation testing population on IOC because we did not have norms for that test.

successful students also scored significantly higher on Analytical Reasoning, Number Series, Number Facility, Incomplete Open Cubes, Number Memory, and the two vocabulary tests. The fact that successful students excel on tests of aptitudes that are also related to engineering, such as Incomplete Open Cubes, Analytical Reasoning, and numerical abilities, is logical. The students in the Stevens Institute of Technology (SIT) study (Technical Report 97, Volumes 1 & 2) showed a somewhat different pattern than those in the current study in that students who successfully completed their engineering degrees at SIT scored High on Structural Visualization and low on English Vocabulary and Tonal Memory. The current study found many more significant differences than did the SIT study, along with similar differences for structural visualization (at least as measured by the Incomplete Open Cubes test) but contrary findings regarding English Vocabulary and Tonal Memory. It could be that roughly 60 years after the SIT study, the successful completion of the engineering degree necessitates greater numerical and reasoning ability than it did previously (although Analytical Reasoning was not given in the SIT study).

The finding here for Analytical Reasoning is similar to that for the Princeton engineering study (Technical Report 654) and makes sense inasmuch as Analytical Reasoning involves working with logical structures of ideas, which would seem to be important in engineering. Given the findings for Number Series, which measures an ability to reason with numbers, along with Analytical Reasoning, it can be concluded that reasoning is related to success in engineering school, which is consistent with the results of other studies, as well. However, Inductive Reasoning showed no relationship with graduation, which may be due to the speeded nature of the test.

The findings for Number Facility and Number Memory are consistent with the results of other studies, which showed effects for numerical ability--engineering is heavily mathematics-based, so this finding is logical. Finally, English and Mathematics Vocabulary showed sizable relationships with success in completing the program. There may be two explanations for this: (a) having a superior store of knowledge when entering an engineering program is helpful in completing the work, and (b) the traits that have led to acquiring knowledge before college are also valuable in college work.

Engineering majors by degree specialty. Individuals with different degree specialties excelled on different aptitudes. For instance, Mechanical and Other (Civil/Aeronautical/Petroleum/Architectural) majors excelled on the speeded Inductive Reasoning test, while Mechanical and Electrical engineering majors excelled on learning new words (i.e., Silograms). Also, Electrical and Chemical engineering graduates have larger vocabularies for both general English words and for mathematics terms. With respect to spatial aptitude, Mechanical engineering majors excelled on Incomplete Open Cubes and Spatial Visualization over and above the other degree specialties. This finding makes sense in that the study of mechanical engineering would be expected to use visualization aptitude, but other specialties would be expected to use it, too. Similarly, one could anticipate that having relatively large vocabularies would help the Electrical and Chemical majors, but one might think that vocabularies would help students in the other majors, too.

Grade point averages. In terms of grade point averages, the strongest relationships with the Foundation tests were for Mathematics Vocabulary and English Vocabulary, in that order. It is likely that knowing mathematical terms and having a broad English vocabulary are useful in performing well in engineering school, but this finding may also illustrate the principle that past performance tends to predict future performance.

Memory for Design and Foresight were also among the better predictors of performance in the engineering curriculum. The finding for Memory for Design makes sense in that memory for visual images (and associated memory and visualization abilities) could be expected to relate to engineering studies. Regarding Foresight, we would point out that the test, in contrast to Ideaphoria, presents examinees with visual images, using a medium that may be well-suited to engineering-type persons. Also, the ability to focus on long-term goals would certainly be expected to facilitate performance in engineering courses. However, there may also be a role here for imagination (seeing possibilities) that has not been appreciated previously.

CONCLUSIONS

In this section, we will provide some final conclusions about the findings and some directions for future research.

Engineering students as a whole. In this study, the engineering students as a whole were a quite able group. The group on average had High (70th percentile or above) scores on Graphoria, Foresight, Number Series, Memory for Design, Number Memory, and Mathematics Vocabulary.

Successful and unsuccessful students. Engineering students who successfully completed their engineering degree scored significantly higher than students who did not complete their degrees on Analytical Reasoning, Number Series, Number Facility, Incomplete Open Cubes, Tonal Memory, Number Memory, English Vocabulary, and Mathematics Vocabulary.

Engineering majors by degree specialty. Significant differences were seen among various engineering degree specialties for Inductive Reasoning, Incomplete Open Cubes, Spatial Visualization, Silograms, and the two vocabulary tests.

Grade point averages. Regarding aptitude performance in relation to grade-point performance in college: a) Foresight, Memory for Design, and, to a lesser extent, Number Facility were correlated broadly with the mathematics, physics, Basic and Major Sequence, and Engineering GPAs, b) Wiggly Block, Incomplete Open Cubes, and Spatial Visualization were not significantly related to the Major Sequence, Engineering, and overall GPAs, and c) the two vocabulary tests were significantly positively correlated with all grade point averages.

It would be interesting to administer a follow-up questionnaire to a larger sample of engineering graduates. In this study, there were only eight respondents to the questionnaire who were no longer working in engineering, engineering management, or another technical field. Some of the trends in our questionnaire data here might reach statistical significance with a larger sample. For example, respondents who left the field scored about one-third of a standard deviation lower on Incomplete Open Cubes (one of the visualization tests) than respondents who remained in engineering or technical work: this difference may have been due to sampling error, but it could also be a substantive effect that would reach significance in a larger study.

A second possibility for future research would be to pursue the role of visualization aptitude more extensively by administering the Foundation's Paper Folding test, which was not given here, to a sample of engineering students and/or follow-up participants.

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Appendix A

Procedures Used to Derive Grade Point Averages

The procedures we used to derive the various GPAs were quite straightforward. First, we followed identical procedures to obtain the American Government and History GPAs. For American Government we found the first two three-credit American Government courses listed on the transcript for each student and derived the average. Specifically, we assigned each grade a point value, namely, A = 4, B = 3, C = 2, D = 1, F = 0. We then derived GPAs. For example, if an individual received an “A” and a “B” for the two American Government courses, he/she would have a GPA of 3.5 by taking (4 + 3)/2. We followed the same procedure to calculate the GPAs for History.

After American Government and History, we calculated a number of other GPAs as well. To obtain the English GPA, we averaged the grade point values for the courses English 306 and English 316K. To obtain the Mathematics GPA, grades for Mathematics 408C, Mathematics 408D, and Mathematics 427K were averaged. A similar procedure was followed to obtain the Physics GPA, for which Physics 303K, Physics 103M, Physics 303L, and Physics 103N were averaged. To obtain the Science/Mathematics GPA, we averaged the GPAs for Mathematics and Physics plus the grade received for Chemistry 301. The GPAs for Mathematics, Physics, and Chemistry were weighted based on the number of credits for that area. For example, engineering students took 12 credits of Mathematics courses and only one three-credit Chemistry class, Chemistry 301, and so the Mathematics GPA was weighted four times relative to the grade received for Chemistry 301. The Humanities GPA was an average of the GPAs for the subject areas of American Government, History, English, and the individual courses taken for Fine Arts/Humanities and Social Science.

Of the last four GPAs shown in Table 4, three were derived directly from engineering courses (Basic Sequence, Major Sequence, and Engineering GPAs), while Overall GPA was the overall GPA across all engineering and non-engineering courses. Within the UT-Austin School of Engineering there are a series of Basic and Major Sequence courses that differ based on the student’s specialization within engineering, e.g., chemical, mechanical, aeronautical, and so on. There are roughly 46 and 43 credits, on average, of Basic and Major Sequence courses, respectively, for each major. The Basic Sequence courses are typically taken in the freshman and sophomore years and include subject areas such as English, Mathematics, Physics, and so on. Conversely, Major Sequence courses: a) are predominantly engineering courses, b) are typically taken in the junior and senior years, and c) are specific to the engineering major being pursued.

Table 1

Scales in the Johnson O'Connor Research Foundation Standard Battery

Name	Reliability[a]	Trait measured
Graphoria, Wks. 703 AB	.96	Clerical speed and accuracy; measured by Number Checking, which involves quickly comparing pairs of numbers to see whether they are the same or different.
Ideaphoria, Wks. 161 AM/CM	.97	Rate of flow of ideas (ideational fluency).
Foresight, Wks. 307 AO/CO	.97	Seeing possibilities.
Inductive Reasoning, Wks. 164 MB	.84	Quickness in seeing relationships among separate facts, ideas, or observations.
Analytical Reasoning, Wks. 244 G*[b]	.83	Ability to arrange ideas into a logical sequence.
Number Series, Wks. 707 BB	.87	Ability to reason (solve problems) with numbers.
Number Facility, Wks. 436 JA	.86	Ability to perform arithmetic operations quickly.
Wiggly Block, Wks. 34555/6 AH	.73	Ability to visualize three-dimensional forms.
Incomplete Open Cubes, Wks. 709 A*[c]	.78	Ability to visualize three-dimensional forms.
Spatial Visualization, Wks. 34555/6 AH + IOC	—	Ability to visualize three-dimensional forms. Measured in this study by Wiggly Block (reconstructing a three-dimensional block) and Incomplete Open Cubes (rotating cube fragments to determine compatibility).

(*table continues*)

Table 1 (*continued*)

Name	Reliability	Trait measured
Subjective vs. Objective Personality, Wks. 35 AQ	.89	Distinction between individuals whose instinctive mental associations resemble those of a large percentage of other persons, and individuals whose associations are unlike those of the majority. The former are said to have objective personalities; the latter, subjective personalities. (Describes how well-suited a person is for working in a group [Objective] versus working on one's own as an individual [Subjective].) Measured by the Word Association test.
Tonal Memory, Wks. 498 BQ	.92	Ability to remember sequences of tones.
Pitch Discrimination, Wks 315 FE	.80	Ability to perceive fine differences in pitch.
Rhythm Memory, Wks. 366 BD	.73	Ability to remember complex rhythmic patterns.
Memory for Design, Wks. 294 UO	.80	Memory for straight-line patterns.
Silograms, Wks. 376 AJ	.92	Associative memory for verbal material.
Number Memory, Wks. 165 AO	.82	Memory for numbers.
Observation, Wks. 744 B*[d]	.72	The ability to retain a mental image of various objects in the mind and quickly perceive any changes in the nature or position of an object.
Finger Dexterity, Wks. 16 ED	.86	Speed and accuracy in manipulating small objects with one's fingers.

(*table continues*)

Table 1 (*continued*)

Name	Reliability	Trait measured
Tweezer Dexterity, Wks. 18 JO	.93	Speed and accuracy in handling small objects with tweezers.
English Vocabulary, Wks. 690 AC/BC/CC	.96	Knowledge of the meanings of non-technical English words.
Mathematics Vocabulary, Wks. 694 AB	—	Knowledge of terms used in mathematics.

[a] Source for reliability coefficients is Statistical Bulletin 1988-2 except for Analytical Reasoning (see below), Number Facility (Statistical Bulletin 2001-3), Incomplete Open Cubes (see below), and Observation (see below).
[b] The software engineers were given an experimental version of the Analytical Reasoning test, Wks. 244 G*, which differed from Wks. 244 HA on only one of the thirteen items. Norms for Wks. 244 HA were used in scoring, and the reliability coefficient for Wks. HA (Technical Report 1992-1) is given here.
[c] Technical Report 1988-5 provides a reliability coefficient for Incomplete Open Cubes.
[d] The software engineers took an experimental version of the Observation test, Wks. 744 B*. The reliability coefficient reported here is based on data from 281 unselected cases from the Foundation's New York office (Statistical Bulletin 2007-1).

Table 2
Aptitude Scores for Engineering Students Based on Graduation Status

	Overall				Degree Completion Status						
					Successful			Unsuccessful			
Test	*M*	*PC*	*SD*	*N*	*M*	*SD*	*N*	*M*	*SD*	*N*	*d*
GR	170.90	77.60	27.70	254	173.74	28.25	123	168.24	27.02	131	.18
ID	260.64	66.17	59.76	254	262.15	55.24	123	259.23	63.90	131	.04
FO	54.86	72.34	18.51	253	56.93	18.75	122	52.94	18.14	131	.22
IR	148.88	60.24	20.46	254	148.92	19.50	123	148.84	21.39	131	.00
AR	66.70	58.87	11.79	254	68.38	11.94	123	65.13	11.47	131	.27*
NS	26.51	77.60	3.19	254	27.03	2.98	123	26.02	3.31	131	.23*
NF	100.27	64.63	13.25	254	102.23	12.84	123	98.43	13.41	131	.24*
WB	317.67	58.86	89.34	253	327.34	89.69	123	308.51	88.37	130	.19
IOC	20.15	N/A	7.58	181	21.15	6.46	101	18.90	8.67	80	.30*
SV	0.00	N/A	1.00	181	0.10	0.95	101	-0.13	1.05	80	.23
TM	58.73	57.44	12.83	252	60.37	12.32	122	57.19	13.15	130	.23*
PD	65.36	57.75	9.86	254	65.68	10.14	123	65.06	9.62	131	.06
RM	46.96	55.75	4.28	253	47.28	4.32	123	46.65	4.24	130	.13
MD	109.85	76.93	23.60	253	111.96	23.73	123	107.85	23.39	130	.16
SI	26.67	69.07	8.39	254	27.65	8.39	123	25.75	8.32	131	.20
NM	102.75	70.49	25.78	254	107.29	26.01	123	98.49	24.91	131	.31*
OB	69.31	N/A	11.02	250	68.44	10.35	122	70.13	11.61	128	-.15
FD	76.73	55.26	11.49	253	76.94	11.74	122	76.53	11.30	131	.03
TD	46.34	56.90	16.61	254	48.07	16.20	123	44.71	16.89	131	.19
WA	15.15	N/A	7.59	253	15.42	7.00	122	14.91	8.12	131	.06
EV	141.47	66.72	29.68	246	145.81	30.11	119	137.39	28.79	127	.29*
MV	38.64	88.77	4.97	251	39.75	4.77	121	37.61	4.95	130	.28**
WS	258.80	N/A	35.12	254	260.41	35.69	123	257.29	34.65	131	.08

(*table continues*)

Table 2 (*continued*)

Note. Column heads: *M* = mean test raw score, *SD* = standard deviation, *N* = number of examinees, and *d* = Cohen's *d*, which is an indicator of effect size for the score difference between those who did and did not successfully complete their degree (Cohen, 1988). The values of *d* were calculated using *SD*s from all examinees tested in 1994-95. GR = Graphoria, ID = Ideaphoria, FO = Foresight, IR = Inductive Reasoning, AR = Analytical Reasoning, NS = Number Series, NF = Number Facility, WB = Wiggly Block, IOC = Incomplete Open Cubes, SV = Spatial Visualization (not Structural Visualization because Paper Folding was not administered, but a more meaningful spatial indicator than WB or IOC scores by themselves), TM = Tonal Memory, PD = Pitch Discrimination, RM = Rhythm Memory, MD = Memory for Design, SI = Silograms, NM = Number Memory, OB = Observation, FD = Finger Dexterity, TD = Tweezer Dexterity, WA = Word Association, EV = English Vocabulary, MV = Mathematics Vocabulary, WS = Writing Speed. IOC raw scores are for only the analog items, which necessitate more visualization than the non-analog items (Technical Report 1988-5). SV scores are not raw scores but are instead standardized scores. To calculate the SV standardized scores, we first partialled the IOC analog raw scores and the Wiggly Block raw scores for age. Then, the resulting IOC and WB scores were standardized, summed, and restandardized.

**p* < .05. ***p* < .01.

Table 3
Aptitude Scores for Engineering Students Based on Degree Specialty

	Electrical		Mechanical		Chemical		Other		
Test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*p*
Graphoria	174.44	30.52	173.20	24.98	170.03	24.36	174.89	30.22	.96
Ideaphoria	256.09	59.99	279.21	43.13	265.73	29.26	253.02	65.23	.23
Foresight	56.03	19.73	56.73	18.40	56.94	10.85	58.96	21.16	.94
Inductive Reasoning	143.16	19.66	153.75	14.99	148.18	21.82	155.04	20.12	.03
Analytical Reasoning	68.17	14.42	70.44	10.18	72.00	9.74	64.60	8.44	.17
Number Series	26.96	3.29	27.22	2.66	27.49	2.63	26.71	2.96	.86
Number Facility	100.84	13.59	105.41	11.72	98.77	11.95	103.17	12.79	.31
Wiggly Block	337.64	95.14	346.46	92.16	314.92	72.02	292.72	77.24	.10
Incomplete Open Cubes	22.12	5.38	23.37	4.97	21.45	5.26	16.84	8.34	<.01
Spatial Visualization	.19	.94	.43	.88	.15	.76	-.43	.97	.01
Tonal Memory	15.79	7.41	14.12	7.21	15.78	7.78	15.96	5.65	.78
Pitch Discrimination	61.64	12.16	59.37	12.96	58.43	12.05	60.00	12.52	.76
Rhythm Memory	65.13	12.19	67.00	9.31	66.93	6.38	64.63	8.32	.38
Memory for Design	47.61	4.42	46.93	5.00	45.64	3.62	47.90	3.55	.39
Silograms	114.16	23.48	114.96	24.82	104.01	23.73	108.52	22.95	.05[a]
Number Memory	29.40	7.24	27.81	8.47	28.09	8.73	23.88	9.40	.31
Observation	107.93	25.47	112.40	25.34	108.82	22.54	99.58	28.95	.11
Finger Dexterity	67.08	9.78	72.23	10.04	65.50	13.12	68.38	9.53	.97
Tweezer Dexterity	77.00	14.07	77.62	8.12	75.84	10.37	76.62	11.37	.28
Word Association	45.64	15.83	47.74	15.03	54.82	12.85	49.61	19.16	.72
English Vocabulary	150.30	31.76	139.58	25.61	170.41	22.71	132.69	26.39	<.01
Mathematics Vocabulary	41.16	4.11	39.32	4.41	40.49	4.54	37.17	5.50	<.01
Writing Speed	262.56	34.81	257.52	30.90	268.00	37.07	255.54	42.13	.68

Note. The Other degree specialty consisted of a combination of the Civil, Aeronautical, Petroleum, and Architectural engineering specialties. *M* = mean, *SD* = standard deviation. Electrical *N* = 52, Mechanical *N* = 30, Chemical *N* = 14, and Other *N* = 27. [a] The *p* value is .049.

Table 4

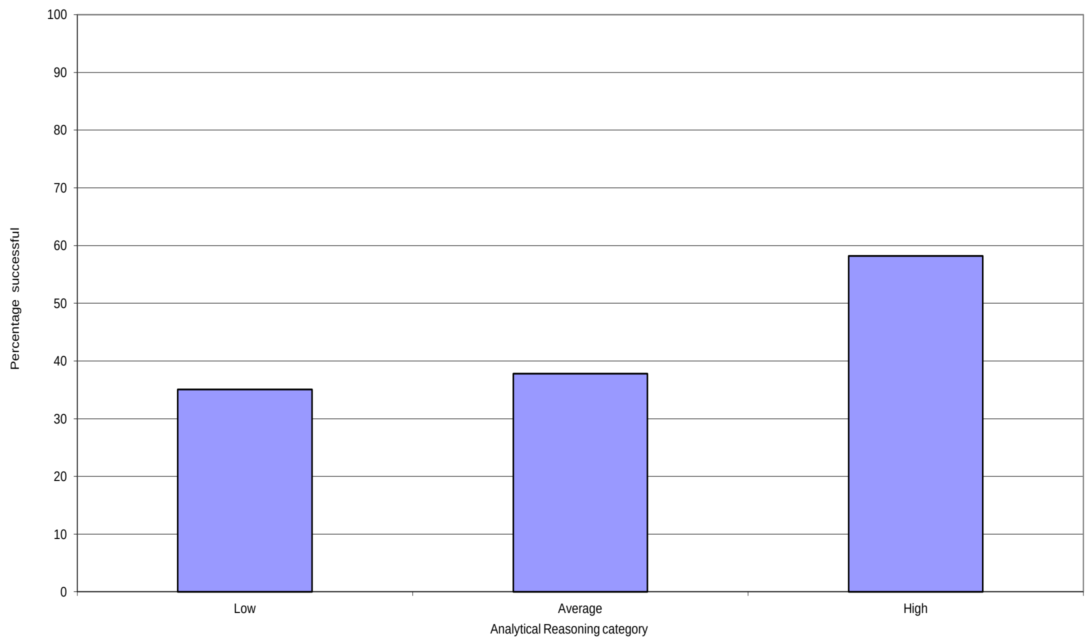
Correlations Between Standard Battery Tests and College Performance GPA

	College Grade Point Averages										
Test	AmGov	History	English	Mathe-matics	Physics	Science/ Math	Humanities	BasSq GPA	MajSq GPA	Engineering GPA	Overall GPA
Graphoria	.16	.24*	.29*	.14	.08	.08	.42*	.17	.24**	.22*	.12
Ideaphoria	.14	.13	.04	.05	.12	.12	.04	.19*	.13	.17	.15*
Foresight	.25	.20	.16	.26**	.20*	.26**	.44*	.33**	.32**	.36**	.18**
Inductive Reasoning	.04	-.07	.08	-.04	-.11	-.07	-.09	-.07	-.05	-.07	-.11
Analytical Reasoning	.24*	.31**	.36**	.18*	.12	.14	.51**	.19*	.17	.19*	.09
Number Series	.10	.02	.10	.12	.24**	.13	.01	.18*	.13	.16	.17**
Number Facility	.24*	.18	.18	.11	.09	.08	.37	.22*	.20*	.22*	.12
Wiggly Block	-.11	.07	.03	.09	.16*	.15	.03	.22*	.09	.16	.05
Incomplete Open Cubes	.26*	.19	.20	.08	.15	.08	.24	.19	.01	.10	.10
Spatial Visualization	.09	.17	.19	.11	.19*	.12	.18	.27*	.05	.16	.12
Tonal Memory	-.04	.27*	.30**	.11	.02	.09	.27	.05	.05	.06	.10
Pitch Discrimination	-.05	.19	.06	.10	.15	.24*	.05	.16	.11	.14	.11
Rhythm Memory	-.22*	.04	.19	.12	.06	.17	-.16	.07	.12	.11	.09
Memory for Design	.04	-.02	.06	.16*	.23**	.23*	-.12	.30**	.19*	.26**	.12
Silograms	.22*	.19	.25*	.17*	.21**	.22*	.25	.15	.05	.11	.15*
Number Memory	.10	.09	.11	.12	.15	.15	.16	.14	.13	.13	.16**
Observation	-.11	.01	-.09	.07	.10	.06	-.43*	.06	.05	.06	-.09
Finger Dexterity	.04	-.01	.13	.07	.00	.03	-.32	.03	.04	.03	.01
Tweezer Dexterity	.03	-.02	-.03	.07	.00	.05	-.10	.16	.11	.15	.08
Word Association	.08	.21	.24*	.09	.17*	.11	.29	.07	.04	.05	.04
English Vocabulary	.32**	.49**	.50**	.29**	.30**	.34**	.70**	.34**	.32**	.36**	.28**
Mathematics Vocabulary	.39**	.54**	.44**	.45**	.52**	.52**	.49*	.61**	.49**	.59**	.47**
Writing Speed	.13	.24*	.03	.10	.08	.11	.27	.14	.19*	.18*	.15*

Note. GPAs: AmGov = American Government, BasSq = Basic Sequence, MajSq = Major Sequence. The range of *N*s across tests for each GPA are: AmGov = 79-83, History = 81-84, English = 75-77, Mathematics = 146-150, Physics = 158-162, Science/Mathematics = 111-114, Humanities = 25-26, BasSq GPA = 119-123, MajSq GPA= 119-123, Engineering GPA = 119-123, Overall GPA = 244-252.
$*p < .05$. $**p < .01$.

Figure 1

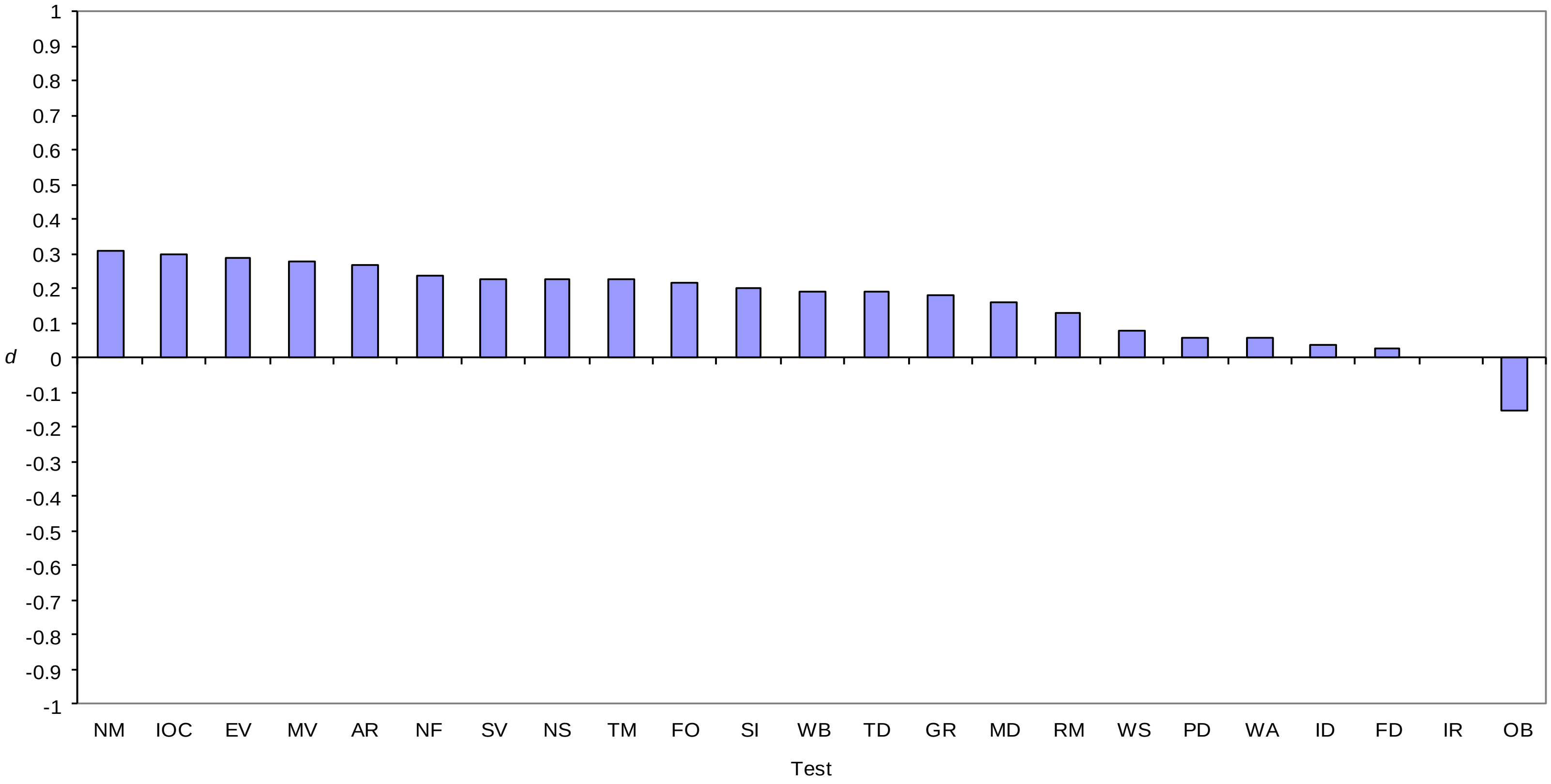
Analytical Reasoning Categories and Success in Engineering School



Note. Low = Analytical Reasoning percentile less than or equal to the 30th percentile. Average = percentile greater than or equal to the 35th percentile and less than or equal to the 65th percentile. High = percentile greater than or equal to the 70th percentile. Success in engineering school was defined as completing the engineering degree program at UT-Austin.

Figure 2

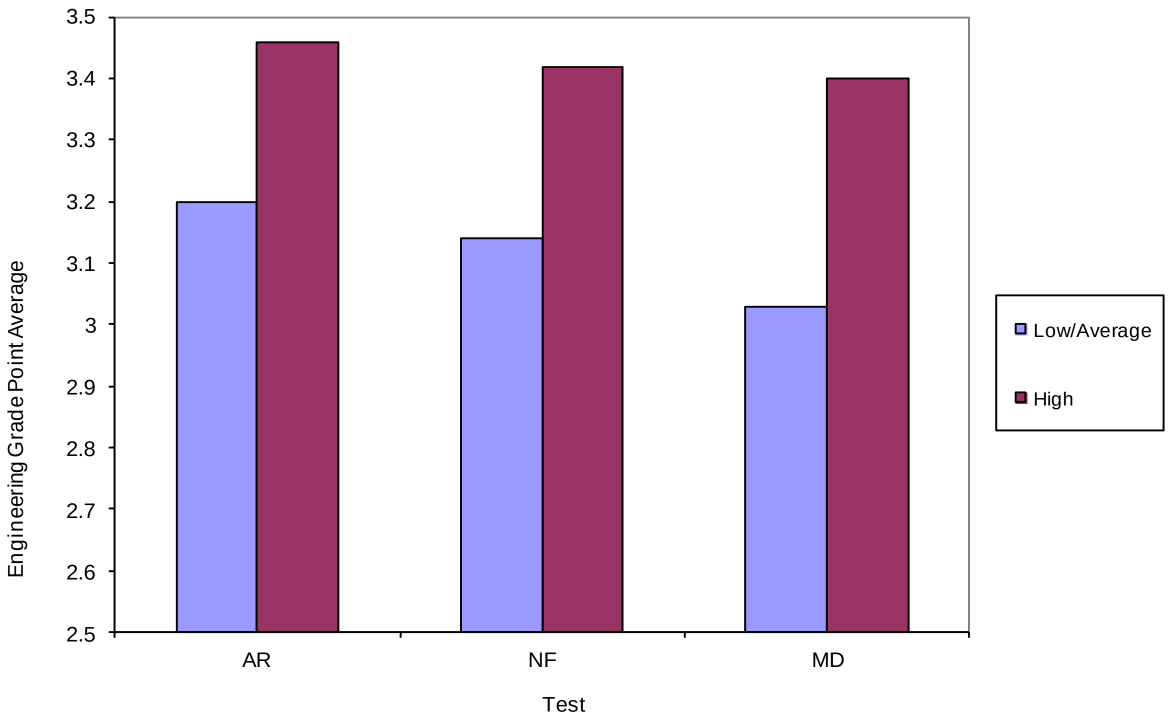
Effect Sizes for Differences Between Successful and Unsuccessful Engineering Students



Note. This figure shows the effect sizes for differences between students who successfully and unsuccessfully graduated with degrees in engineering from UT-Austin on the standard battery tests. *d* = effect size (Cohen, 1988). There is no bar for Inductive Reasoning because *d* = .00.

Figure 3

Engineering Mean Grade Point Averages for Different Ability Levels on Various Standard Battery Tests



Note. Low/Average = low or average Foundation percentiles, i.e., less than or equal to the 65th percentile. High = high Foundation percentile, i.e., greater than or equal to the 70th percentile. The correlations for engineering grade point average with Analytical Reasoning, Number Facility, and Memory for Design, respectively, are statistically significant at the $\alpha = .05$ level.