A LONGITUDINAL STUDY OF ENGINEERING STUDENT PERFORMANCE AND RETENTION. I. SUCCESS AND FAILURE IN THE INTRODUCTORY COURSE†

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ABSTRACT

A profile of 123 students enrolled in an introductory chemical engineering course has been assembled. The information collected includes data on family and educational backgrounds, profiles on the Myers-Briggs Type Indicator and the Learning and Study Strategies Inventory, and responses to a questionnaire regarding attitudes and expectations. Student performance in the introductory course was correlated with the assessment data. The results suggest several significant predictors of success or failure in the introductory course, and by extension, in the chemical engineering curriculum.

INTRODUCTION

The United States will experience a serious shortage of engineers over the next two decades. Part of the reason is demographics: the college-age population has been steadily declining since 1983, will continue to do so through 1996 for a total drop of 25%, and will stay roughly constant at that level until about 2005.[1] Aggravating the situation is a rapid decline in student interest in science and engineering. Between 1966 and 1988 the proportion of college freshmen planning to major in a technical field fell by close to a factor of two.[2] Moreover, many of those who enter engineering curricula drop out, with attrition rates of 50% and minority dropout rates of 70% and higher being relatively common. For more than a decade, only about 30% of the entering African-American freshman engineering class have completed their degrees.[1]

Various instructional approaches, such as collaborative learning and writing across the curriculum, have been proposed as vehicles to increase retention and to improve the quality of learning. However, most experiments with these methods have been carried out on a one-shot basis: a professor tries a new method in a course and assesses student performance and attitudes; many students respond well to the new method; and most of them never see anything like it again. Conclusions about the long-term benefits of methods tested in this manner are at best tenuous. One course is unlikely to provide enough practice in the new methods to produce students who, for example, habitually probe deeply into problems and seek innovative solution methods when traditional ones fail. With these observations in mind, in the fall of 1990 we began a longitudinal project with a cohort of students enrolled in the introductory chemical engineering course. One of us (RMF) will teach these students in a sequence of courses spread over five semesters, using a variety of instructional methods including extensive collaborative (team-

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based) learning, routine assignment of open-ended problems and problem formulation exercises, and other techniques designed to address the spectrum of learning styles found in all engineering classes.[3] Our hypothesis is that the students participating in this program will remain in engineering through graduation to a greater extent, earn higher grade point averages in engineering, and develop more positive attitudes about engineering and about their own capabilities than do students who go through the traditionally taught curriculum.

In the first semester of the study, we collected data on the students including (a) SAT scores (mathematics and verbal examinations), (b) admissions index (a predicted grade point average calculated for entering freshmen based on SAT scores and high school performance records), (c) freshman year grade point average and grades in selected freshman courses, (d) responses to questionnaires regarding family and educational background, motivations for choosing engineering and chemical engineering, level of confidence in the choices, study and leisure habits, and various attitudes and expectations, (e) profiles on Self-scorable Form G of the *Myers-Briggs Type Indicator*®, a widely-used instrument that assesses positions on four scales derived from Carl Jung's theory of psychological types, and (f) profiles on the *Learning and Study Strategies Inventory*®, an instrument that assesses students' test-taking skills and strategies, motivation to learn, and anxiety levels.

This paper summarizes the principal results of these assessments and the performance of the group in the first course. A report containing the detailed data is obtainable upon request from the authors.[4]

PROFILE OF A CLASS

North Carolina State University is the state's land grant institution. The total student enrollment is roughly 25,000, with roughly 85% of the undergraduates coming from North Carolina. The College of Engineering is one of the ten largest engineering schools in the country. In the fall of 1990 the chemical engineering department experienced a surge in enrollment, presumably as a result of a strong job market in the previous two years; the enrollment of 123 in the introductory sophomore course (CHE 205—Chemical Process Principles) represented an increase of about 30% over the previous year.

Early in the introductory course, the students filled out questionnaires in which they provided information about their family backgrounds, motivations for selecting engineering and chemical engineering as major fields of study, and levels of confidence in their choices of curriculum and in themselves as learners. They also completed the *Myers-Briggs Type Indicator* and the *Learning and Study Strategies Inventory*. The principal results of these assessments are summarized in Tables 1–6.

Table 1 shows that the class was predominantly white and male (although the female enrollment of almost 30% is somewhat above the national average). Slightly less than half of the students had rural or small town backgrounds, and 65% of their fathers and 52% of their mothers were college graduates.

When asked to select one to three major influences in their choice of engineering as their major field of study (Table 2), well over half cited their aptitudes in science and mathematics; about half cited an interest in the field; slightly less than half cited potential material benefits (mobility and high pay); many cited the influence of a role model; and fewer than 10% mentioned a high school advisor or an open house or career day program. After three weeks in the course, about 85% claimed confidence in their choices of both engineering and chemical engineering, a figure that would decline as the semester proceeded.

Slightly more than 20% of the students had outside jobs that involved more than 10 hours a week and 42% were planning to participate in the co-op program or were leaning in that direction (Table 3). On the average they were anxious about grades, somewhat overconfident about their chances of success in the introductory course, and more inclined to attribute academic success to hard work than natural ability (Table 4).

The MBTI profiles shown in Table 5 are consistent with results from previous studies of engineering undergraduates.[5] There are

- slightly more introverts than extraverts \item more sensors (practical, methodical, interested in "real-world" applications) than intuitors (imaginative, comfortable with theories and models)
- significantly more thinkers (make decisions based more on rules and logic than on feelings and emotions) than feelers (vice versa) \item significantly more judgers (inclined to set and follow agendas) than perceivers (inclined to keep their options open and shift with changing circumstances).

The LASSI profiles in Table 6 show that the entering chemical engineering students are somewhat better motivated and equipped with study skills and slightly more anxious about school than the average college student who has taken this test.

DATA ANALYSIS

Performance in CHE 205 was measured in two ways, described in more detail in the next section. First, each student had a weighted average grade based on homework and test scores; these grades potentially ranged from 0 to 100. Second, students were classified on the basis of weighted average grade and performance on bonus problems into those who passed and those who failed CHE 205. The statistical methods used differed for these two measures of course performance.

The categorical variables summarized in Tables 1–5 were cross-classified with the dichotomous pass/fail variable. Chi-square tests were used to test for association between performance in CHE 205 and each of the categorical variables. For certain variables, the cross-classification table had small expected frequencies in some cells, rendering the chi-square test inappropriate. In these cases, and for all two-by-two tables, Fisher's exact test for independence between two categorical variables[6] was used instead of the chi-square test. This test utilizes the exact hypergeometric distribution rather than the chi-square distribution. The two-sided Fisher's test, like the chi-square test, is designed to detect any departure from independence between two categorical variables irrespective of the direction of the deviation, while a one-sided test detects deviations in a specified direction.

The weighted average grades were analyzed using methods appropriate for quantitative rather than categorical variables. Pearson correlations were used to test for association between weighted average grade and various quantitative variables including college admission criteria, freshman year grades, and scores on the LASSI. A positive (negative) correlation coefficient implies a positive (negative) linear association between two numerical variables. Other statistical methods employed for the weighted average grades were t-tests and multiple regression.

WHO PASSES CHE 205?

In CHE 205 there were three tests and a final examination, 14 homework assignments, and a set of bonus problems. Students did the homework in groups of three or four and took the tests individually. Weighted average grades were calculated based on the average homework grade, two highest test grades, and final examination grade. The students were rank-ordered by weighted average grades and letter grades were assigned to numerical ranges. A "gray area" occurred between each pair of adjacent letter grades; performance on bonus problems determined whether a student in a gray area received the higher or lower grade. Satisfactory work on at least seven bonus problems was a necessary condition for an A in the course.

It takes a C or better in CHE 205 to proceed to the second course in the chemical engineering curriculum. In the discussion that follows, "passing" means earning a grade of C or better and "failing" means earning a D or F or dropping the course. In the final grade distribution, there were 28 A's, 40 B's, 15 C's, 11 D's, and 23 F's, and six students dropped. The total number of "passes" was therefore 83 and the number of "failures" was 40.

The data summarized in Tables 1–5 provided the basis for a variety of class groupings, e.g. into males and females, ethnic minority and white students, students from rural and urban communities, sensors and intuitors, etc. We analyzed the performance levels of students for many such categorizations, using a Fisher's exact test when there were two comparison groups or when some cells in larger tables had very small expected frequencies, otherwise using a chi-square test. We combined categories on the background questionnaire when sample responses were very low in one of the categories and the combination was logical; for example, we lumped responses of "very doubtful" and "somewhat doubtful" to one question into a single category labeled "doubtful." Since some students did not complete certain of the assessment instruments, the sample usually did not equal the full class complement of 123 but varied between 117 and 120.

For example, 68% of 34 females and 67% of 89 males in the sample passed the course with a grade of C or better. A two-tailed Fisher's exact test indicates that this difference is not significant at any level. On the other hand, 80.0% of 65 students from a suburban or urban background and 54.6% of 55 students from a rural or small town background passed with C or better. Fisher's exact test shows that the difference in this case is highly significant: the null hypothesis that the probability of passing is equal for both groups is rejected at a level of significance $p=0.003$.

Significant ($p<0.1$) differences in passing frequencies were found for several sample groupings. The probability of passing CHE 205 was

- Greater for students from suburban or urban backgrounds (80% of 65) than from rural or small town backgrounds (54.6% of 55). [$p=0.003$]

- Different for students who enter the course expecting to earn A's (84% of 50), B's (58% of 60), C's or lower (50% of 8). [*p*=0.008]
- Different for students who would be satisfied with a grade of C or better (36% of 14), B or better (64% of 64), A (90% of 30), creative work beyond an A (82% of 11). [*p*=0.002]
- Different for students who consider their biggest obstacle to academic success to be heavy course demands (73% of 82), poor work/study habits (64% of 28), lack of talent for the subject (38% of 8). [*p*=0.099]
- Greater for students working at an outside job 10 hours per week or less (72% of 94) than for students working 11 or more hours per week (56% of 25). [*p*=0.094] The passing probabilities for students working 0-5 hours (72% of 73) and 6-10 hours (71% of 21) were almost identical.
- Greater for students who spend between 2 and 12 hours per week on extracurricular activities (75% of 91) than for students who spend more than 12 hours per week (38% of 8) [*p*=0.039] {\em and} for students who spend less than two hours per week (55% of 20) [*p*=0.071].
- Greater for students who say they do not spend more than a "typical" amount of time on social activities (72% of 110) than for students who say they spend more than a typical amount of time on them (33% of 9). [*p*=0.025]
- Different for students who rate their academic preparation for the course to be less than average (38% of 13), average (66% of 59), better than average (80% of 46). [*p*=0.013]
- Different for students whose fathers graduated from college (80% of 71), attended but did not complete college (87% of 15), never attended college (36% of 24). [*p*< 0.001] The mother's educational background did not have a significant effect on the passing probability. The patterns were the same for male and female students analyzed separately.
- Greater for MBTI intuitors (82% of 49) than for sensors (63% of 67) [*p*=0.027].

Some noticeable variations in passing probabilities were not significant at the 0.1 level, in some instances due to small sample sizes in some of the cells. For example, the probability of passing appeared to be

- Greater for white students (69% of 102) than for African-American students (38% of 8).
- Different for students who expect to graduate in 4 years (85% of 26), 4.5 years (65% of 54), 5 years (66% of 38).
- Different for students who would choose as an outcome for the course getting a good grade without working (50% of 2), improving their study skills (52% of 25), discovering hidden talents (64% of 14), finding the class interesting and enjoyable (76% of 78).
- Greater for MBTI extraverts (77% of 56) than for introverts (65% of 60).
- Different for different MBTI temperaments: SJ (64% of 51), SP (56% of 16), NT (84% of 31), NF (78% of 18).
- Different for different MBTI function pairs: ST (61% of 49), SF (67% of 18), NT (84% of 31), NF (78% of 18).

Other comparisons that were not statistically significant involved gender (almost identical passing rates for males and females), difficulty of choosing engineering as a major (a slightly higher passing rate for those for whom engineering was an obvious or easy choice), certainty about choice of chemical engineering (almost identical passing rates for those who were doubtful, uncertain, and sure), current level of stress (a slightly higher passing rate for those who claimed to be at low stress levels), and MBTI dimensions besides those named (slightly higher passing rates for judgers over perceivers and for thinkers over feelers).

One additional comparison is intriguing, albeit not statistically significant. It appears that the more students believed they knew what chemical engineers do, the less likely they were to pass the course. The passing rate was 50% for the 6 who felt they could give a detailed description of the practice of chemical engineering; 65% for the 69 who believed they had a good idea about it; 76% for the 42 who had at best a rough idea; and 100% for the two who had no idea at all. We think this result is telling us something but we are not quite sure what.

WHAT CORRELATES WITH PERFORMANCE IN CHE 205?

Weighted average grades earned by students who completed the course (mean=75.5, standard deviation=15.7) were correlated with various college admission criteria (admissions index, SAT mathematics and verbal scores), freshman year grades (overall GPA, grades in calculus, chemistry, physics, and English courses—A=4.0), and scores on the Learning and Study Strategies Inventory. Pearson correlations significant at the 0.1 level include the following:

College admission criteria

- Admissions index [r=0.49, p<0.0001]
- SAT-Math [r = 0.47 , p<0.0001]
- SAT-Verbal [r = 0.29 , p = 0.0054]

Freshman year grades

- GPA [r=0.66 , p<0.0001]
- MATH 141 (first semester calculus) [r=0.46 , p<0.0001]
- MATH 241 (second semester calculus) [r=0.62 , p<0.001]
- CHEM 101 (first semester chemistry) [r=0.47 , p<0.0001]
- CHEM 107 (second semester chemistry) [r=0.61 , p<0.0001]
- PHYS 205 (first semester physics) [r=0.62 , p<0.0001]
- ENG 111 (first semester English) [r=0.26 , p = 0.013] .

LASSI scores

- *MOT* (a measure of tendency to take responsibility for doing what it takes to succeed in coursework, e.g. reading the text, completing homework assignments, preparing for tests, etc.) [r = 0.24 , p = 0.015]
- *SMI* (a measure of ability to select main ideas from lectures and readings) [r = 0.17 , p = 0.082]
- *TST* (a measure of test-taking strategies) [r = 0.23 , p = 0.020] .

MBTI difference scores

S–N (number of sensing answers minus number of intuitive answers on the Self-Scorable Form G of the MBTI) [$r = -0.19$, $p = 0.047$]

The last result indicates that intuitors tended to get higher grades than sensors, consistent with the result given previously for passing frequencies. The mean weighted average grade obtained by intuitors was 79.5 and that for sensors was 72.4, a difference significant at the 0.015 level by t-test. Other grade differences between opposites on MBTI dimensions were not statistically significant at the 0.1 level.

Multiple regression

We carried out a multiple linear regression with the weighted average CHE 205 grade as the dependent variable, beginning with all of the listed college admission criteria and freshman year grades as independent variables and using backward elimination to drop variables with low levels of significance. The final model retained grades in CHEM 107 and PHYS 205 as independent variables and yielded an r^2 value of 0.48, meaning that variations in grades in these two first-year courses accounted for 48% of the variance in the CHE 205 grade. The overall freshman-year GPA by itself accounted for 44% of the variance.

SUMMARY AND CONCLUSIONS

Data have been collected on backgrounds, attitudes, learning style preferences, study skills, and freshman-year performance records of 123 students in an introductory chemical engineering course. The results were analyzed to determine factors in a student's background that might be significant predictors of success or failure in the course, and by extension, in the chemical engineering curriculum.

The probability of passing the course with a grade of C or better depended on the type of home community (urban/suburban > rural/small town),* time devoted to an outside job (less than 10 hours/week > more than 10 hours/week), time devoted to extracurricular activities (2-12 hours/week > less than 2 or more than 12 hours/week), father's educational level (some college education > no college education), and sensing/intuition preference on the Myers-Briggs Type Indicator (intuitors > sensors). The weighted average grade in the course correlated positively with SAT mathematics and verbal scores, freshman-year grade point average, grades in selected freshman mathematics, physics, chemistry, and English courses, several scores on the Learning and Study Strategies Inventory (LASSI), and the numerical difference score on the sensing-intuitive scale of the Myers-Briggs Type Indicator (intuitors > sensors).

These results have interesting implications for academic advisors and counselors. Early identification of students who are potentially at risk in the introductory engineering course may help advisors devise timely and effective interventions to help these students. For example, first-year students planning to enter chemical engineering might be targeted for special counseling if they have done poorly in their chemistry or physics courses, and especially if they have done poorly in both. The advisor might alert them to the association between low grades in those

* That is, students who grew up in urban or suburban communities were significantly more likely to pass than students from rural or small town home communities.

courses and failure in the introductory chemical engineering course. He/she may then suggest that the students seek timely assistance as questions or problems arise, making them aware of tutorial programs and other academic resources available to them. The advisor might also help these students plan their course loads wisely, discouraging attempts to "stay on track" by scheduling too many technical courses in a semester or quarter.

Finally, the data base generated in this study should make it possible to determine the types of students who respond well to alternative methods of instruction and the types who respond poorly. Such information will be the subject of future papers.

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TABLE 1. DEMOGRAPHICS, HOME, AND FAMILY

Category	Distribution	N
Sex	Female—29%, Male—71%	124
Race	African-American—6%, Asian/Asian-American—5%, Hispanic—2%, Native-American—3%, White—84%	124
Home town	Rural—14%, Small town—32%, Suburban—37%, Urban—17%	120
Father's education	<HS—6%, HS—15%, Some coll.—14%, Bachelor's degree—41%, Advanced degree—24%	110
Mother's education	<HS—2%, HS—26%, Some coll.—20%, Bachelor's degree—35%, Advanced degree—17%	110

TABLE 2. CURRICULUM CHOICE

Category	Distribution	N
Top 3 significant influences on choice of engineering	Sci/math aptitude—62%, interest in field—58%, mobility-pay—47%, socially important problems—32%, role model/positive experience—22%, family member—14%, open house/career day—9%, HS advisor—8%, friend/classmate—6%, summer program—6%, other—11%	120
Certainty of choice of engr.	Comfortable choice—62%, tough choice but convinced it's right—18%, still wavering—20%	119
Top 3 significant influences on choice of CHE	Interest in field—75%, mobility-pay—52%, family member—18%, role model/positive experience—18%, friend/classmate—15%, freshman orientation class—9%, other—22%	120
Certainty of choice of CHE	Very sure—24%, fairly sure—61%, uncertain—13%, doubtful—2%	119
Certainty of graduating in CHE	Very sure—27%, fairly sure—59%, no idea—7%, Somewhat doubtful—5%, highly doubtful—2%	119
Knowledge of what chem. engrs. do	Detailed—5%, fairly good idea—58%, rough idea—35%, almost no idea—2%	119

TABLE 3. OUTSIDE ACTIVITIES

Category	Distribution	N
Work (hr/wk)	<5—61%, 6-10—18%, 11-20—17%, 21-30—3%, >30—2%	119
Social life	Heavy—8%, typical—66%, limited—22%, very limited—5%	119
Plan to coop?	Yes—20%, probably—22%, don't know—20%, probably not—28%, no—11%	118
Guess time to graduate	4 years—22%, 4½ years—46%, 5 years—32%	118

TABLE 4. SELF-ASSESSMENT (AFTER THREE WEEKS)

Category	Distribution	N
Anxious about school?	Very—29%, somewhat—45%, slightly—23%, no—3%	119
Anxious about 205?	Very—32%, somewhat—52%, slightly—15%, no—1%	119
Guess final 205 grade (Actual distribution)	A—42%, B—51%, C—5%, D—1%, F—1% (A—23%, B—12%, C—9%, D—1%, F—19%, drop—6%)	118 (124)
To be satisfied with performance in 205:	After 3 weeks: C or better—11%, B or better—54%, A—25%, creative work—9% After 8 weeks: Pass—2%, C or better—24%, B or better—48%, A—24%, creative work—3%	119 109
My biggest obstacle to Doing well in 205 is:	Other demands—69%, poor work habits—23%, lack of talent—7%, lack of instructor support—1%	119
If I succeed beyond expectations it will be because:	I have ability—30%, I work extra hard—62%, I get extra help—4%, course and instructor are easy—3%, I get lucky—1%	117
If I don't perform at the level I hope to it will be because:	I lack ability—11%, I don't work enough—64%, course & instructor are too demanding—15%, personal crisis occurs—10%	119

TABLE 5. MYERS-BRIGGS TYPE INDICATOR PROFILES (N=116)

Category	Distribution			
Dimensions	E—48%	I—52%	(E=extravert, I=introvert)	
	S—58%	N—42%	(S=sensor, N=intuitor)	
	T—69%	F—31%	(T=thinker, F=feeler)	
	J—62%	P—38%	(J=judger, P=perceiver)	
Functions	ST—42%	SF—16%	NT—27%	NF—15%
Temperaments	SJ—44%	SP—14%	NT—27%	NF—15%
Types	ENFJ— 1.7%	ENFP—9.5%	ENTJ— 6.0%	ENTP—4.3%
	ESFJ— 6.9%	ESFP—1.7%	ESTJ— 11.2%	ENTP—6.9%
	INFJ— 2.6%	INFP—1.7%	INTJ— 7.8%	INTP— 8.6%
	ISFJ— 5.2%	ISFP—1.7%	ISTJ— 20.7%	ISTP—3.4%

TABLE 6: LASSI SCORES (N=109)

Scale[†]	**Mean**	**SD**	**Percentile**[‡]
ATT	32.5	6.0	55
MOT	31.9	5.3	59
TMT	24.8	6.0	59
ANX	25.6	6.7	48
CON	27.3	5.7	62
INP	28.2	5.4	62
SMI	19.3	3.4	63
STA	24.8	5.5	53
SFT	26.1	5.4	56
TST	30.4	5.7	54

[†] Scale definitions:

ATT = Attitude and interest in school
MOT = Motivation, diligence, self-discipline, willingness to work hard
TMT = Use of time management principles for academic tasks
ANX = Anxiety about school performance (high score=low anxiety)
CON = Concentration and attention to academic tasks
INP = Information processing (ability to supply meaning and organization to new information)
SMI = Selecting main ideas and recognizing important information
STA = Use of study aids (highlighting, underlining, writing summaries,...)
SFT = Self-testing, reviewing, preparing for classes
TST = Test-taking strategies and preparing for tests

[‡] Percentile of mean score in relation to nationwide population of students taking the test