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Factors Impacting Retention and Success of Undergraduate Engineering Students

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Stephen Krause is professor in the Materials Science Program in the Fulton School of Engineering at Arizona State University. He teaches in the areas of introductory materials engineering, polymers and composites, and capstone design. His research interests include evaluating conceptual knowledge, misconceptions and technologies to promote conceptual change. He has co-developed a Materials Concept Inventory and a Chemistry Concept Inventory for assessing conceptual knowledge and change for introductory materials science and chemistry classes. He is currently conducting research on NSF projects in two areas. One is studying how strategies of engagement and feedback with support from internet tools and resources affect conceptual change and associated impact on students' attitude, achievement, and persistence. The other is on the factors that promote persistence and success in retention of undergraduate students in engineering. He was a coauthor for best paper award in the Journal of Engineering Education in 2013.

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James A. Middleton is Professor of Mechanical and Aerospace Engineering and Director of the Center for Research on Education in Science, Mathematics, Engineering, and Technology at Arizona State University. For the last three years he also held the Elmhurst Energy Chair in STEM education at the University of Birmingham in the UK. Prior to these appointments, Dr. Middleton served as Associate Dean for Research for the Mary Lou Fulton College of Education at Arizona State University for 3 years, and as Director of the Division of Curriculum and Instruction for another 3 years. He received his Ph.D. in Educational Psychology from the University of Wisconsin-Madison in 1992, where he also served in the National Center for Research on Mathematical Sciences Education as a postdoctoral scholar for 3 years.

Jim's research interests focus in the following areas where he has published extensively: Children's mathematical thinking; Teacher and Student motivation in mathematics; and Teacher Change in mathematics. He is currently developing methodologies for utilizing the engineering design process to improve learning environments in Science, Engineering and Mathematics. He has also written on effective uses of educational technology in mathematics and science education as a natural outgrowth of these interests. To fund his research, Jim has garnered over $20 million in grants to study and improve mathematics education in urban schools. He just finished a $1.8 million research grant to model the longitudinal development of fractions, rational number and proportional reasoning knowledge and skills in middle school students, and is currently engaged in a project studying the sustainability of changes in urban elementary teachers' mathematics practices. All of his work has been conducted in collaborative partnerships with diverse, economically challenged, urban schools. This relationship has resulted in a significant (positive) impact on the direction that partner districts have taken, including a significant increase in mathematics achievement in the face of a rising poverty rate.

Dr. Eugene Judson, Arizona State University

Eugene Judson is an Associate Professor of for the Mary Lou Fulton Teachers College at Arizona State University. His past experiences include having been a middle school science teacher, Director of Academic and Instructional Support for the Arizona Department of Education, a research scientist for the Center for Research on Education in Science, Mathematics, Engineering and Technology (CRESMET), and an evaluator for several NSF projects. His first research strand concentrates on the relationship between educational policy and STEM education. This provides policymakers and the educational community an improved understanding of how changes in educational policies impact STEM teaching and learning. His second research strand focuses on studying STEM classroom interactions and subsequent effects on student understanding. He is a co-developer of the Reformed Teaching Observation Protocol (RTOP) and his work has been cited more than 1200 times and his publications have been published in multiple peer-reviewed journals such as Science Education and the Journal of Research in Science Teaching.

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His research takes two distinct but interrelated paths focused on elementary students' learning in science and engineering as well as in-service science teachers' professional development. The first focus involves how language as a learning tool improves students' conceptual understandings, literacy, and representation competencies in science. His second research focus is on how in-service teachers develop their knowledge for teaching science and engineering in argument-based inquiry classrooms. This research is aimed at developing measures of teachers' Pedagogical Content Knowledge (PCK) for adopting the argument-based inquiry approach, as well as developing tools to capture the interactive nature of PCK.

Factors Impacting Retention and Success of Undergraduate Engineering Students

Abstract

Factors impacting student persistence in engineering were examined to assess the impact of a long-term student success initiative for freshman students at a large urban university. Institutional data, classroom observations, faculty interviews and assessments were utilized to determine probable causal factors interacting in predicting student persistence for the first two years of university engineering, and persistence to graduation. Results show that classroom observations as measured by the Reformed Teaching Observation Protocol (RTOP) instrument and faculty attitudes towards student-centered instruction as measured by the Approaches to Teaching Inventory (ATI) instrument were closely related. It was generally found that teacher-centered instructors had lower RTOP scores while student-centered instructors had higher RTOP scores. In the second area of student persistence, the first result was that, of the roughly 50% of students that departed from engineering prior to graduation, 85% of them did so within the first two years while only 15% left in the last two to four years. It was also found that the impact of first time freshman's first mathematics class on persistence and graduation was dramatic. For first-time-freshman students with A or B in a math course above calculus I, 80% persisted to graduation, while students whose first math course was calculus I had 65% persistence to graduation and for students whose first math course was below the level of calculus I had only 35% persistence to graduation. For students at any level who withdrew or received a grade of C or lower, their chances of graduating from engineering were less than 20%. The third area was co-curricular student support programs, experiences, and activities such as Undergraduate Teaching Assistants, Tutoring Center, Supplemental Instruction, and Student Residential Communities; and co-curricular experiences include Undergraduate Research, E2 Freshman Camps, and Professional Societies. The impact of these support programs was shown using an interrupted time series analysis. Persistence growth rates grew from about .98 per year prior to success programs being instituted to 1.6 per year following institution of the reforms. This occurred in spite of the fact that first-time freshman enrollments more than doubled over the studied period. Overall, the results to date indicate that there is a strong need for faculty professional development to shift pedagogy more toward student-centered learning, entering students need to be calculus ready and the students would likely benefit from more effective teaching in early math courses, and finally co-curricular activities appear to improve students' sense of belongingness as well as helping develop students' engineering professional identity.

Introduction

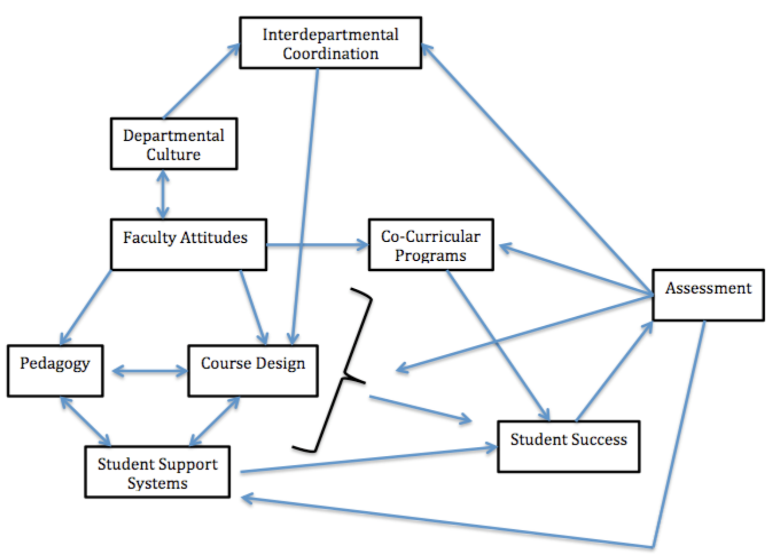
At research institutions, roughly 45% of engineering majors either switch to a non-STEM major or do not complete a 4-year degree.[1,2] The chief culprits of this attrition seem to be located in students’ experiences in the first two years of University.

Chief among the variables that impact student persistence is their sense of belonging in the institution. There is general consensus that persistence in college is a function of the ways in which students view the congruence of the goals and opportunities of the university with their own set of academic values[3,4]—a kind of calibration between the success indicators valued by the student, and those valued by the institution.

Moreover, the affinity the student has for the institution is also a factor, determined by both academic and social systems of the insitution[3]. Research shows that students who make connections with faculty in their chosen field, and who make connections with other students, show significantly better persistence in college than those who remain more isolated. These two factors are among the most critical overall, because they focus on the emotional needs of (typically) young people who are often away from home for the first time, and are just learning the norms, expectations, and practices of university life. STEM coursework in particular has been shown to turn off such young people, to a great extent because faculty are seen as unresponsive and uncaring for freshmen as individuals. Large class sizes and course assignment practices contribute to this phenomenon[5]. Students more often receive poor grades in STEM courses in their first two years than other fields, and they tend to drop out of engineering at a higher rate than other majors. Some research shows that grades in STEM subjects are not as important as the ways students are enculturated, and how their learning needs are addressed. But it is generally acknowledged that students' social and emotional wellbeing works in concert with academic performance in determining their long-term persistence in STEM subject matter[5].

This project studies the impact of these factors and their interactions that occur in a system with sociocultural effects occurring at four levels. These levels include: 1) Student enculturation and academic support systems; 2) Classroom effects, both course design and pedagogy; 3) Departmental Culture; and 4) Interdepartmental Coordination and Interaction (See Figure 1). The current project is utilizing assessment at each level to both determine key areas in need of reform, and to feed back results of innovations to stakeholders at each level. It is hypothesized that effects at each level act as key drivers of student motivation, achievement and persistence. In this paper, we focus on the freshman experience, because of the key role that the first two years of collegiate experience has on students' propensity to remain in major and in college in general.

Figure 1. Key interacting variables influencing student success. Note the unique role placed by assessment.



Theory of Change

Fairweather[6] criticizes the current piecemeal approach to reform of undergraduate STEM education. In particular, he maintains that instructional role cannot be addressed independently from other aspects of the faculty position (in particular research), and from the larger institutional context. He cites an evaluation of over 400 NSF CCLI projects that each found significant empirical evidence of the educational benefits their pedagogical reforms meant to foster, but, little evidence of the spread of successful practices beyond the individual faculty member, much less to others in the department or across colleges[7]. It is likely, then, that the success of interventions is highly dependent on each individual faculty member, mediated by the culture of their academic department. Additionally, it is likely that any single reform (e.g., improvement of a single mathematics course or a few sections of a course) will be ineffective in overcoming the predominant institutional inertia that maintains legacy practices in the face of evidence that the evidence-based practices are more effective. Evidence based practices must be instituted broadly, throughout students' experiences, and they must be coordinated in a coherent model of the determinants and facilitators of student success.

Working Definition

We define evidence-based practices as those innovations (e.g., teaching behaviors, course structures, curricular materials, technological implementation, peer roles and relationships, etc.) that have been shown through empirical studies to have a positive causal impact on desired outcomes (e.g., student learning, persistence, etc.). Each of these has a reasonable empirical warrant, but the conditional effectiveness of each has not yet been established, nor their mutual impact described. Lastly, the departmental culture situating these practices and its effects has not yet been studied. Table 1 illustrates the evidence-based practices currently being developed.

Moreover, such practices must have a theoretical model that describing *why* they are positively causal, and *under what conditions* such practices are likely to be effective[8]. Not all strategies presented as "evidence-based" can meet these criteria. This project attempts to implement strategies showing promise through a reasonable evidentiary warrant, but we wish to establish the *why* and *under what conditions* clauses to create a set of defensible evidence-based practices. Teams involved in redesigning the freshman experience work under the model that substantive, positive change is only accomplished when a number of necessary and sufficient conditions come together. Figure 1 illustrates how classroom/faculty, departmental, and interdepartmental activities must be designed in coordination, and conducted so that each supports the other.

Freshman Experience

As of yet, the research on freshman success has focused on only a few important, but isolated innovations. Among these are 1) Re-design of STEM courses, curriculum, and pedagogy[9]; 2) Design of freshman success courses; 3) Engagement in Co-curricular experiences (e.g., research experiences for undergraduates, involvement in clubs); 4) Design of Student support programs such as Learning Assistants and Supplemental Instruction[10]; and 5) Student residential communities. Briefly, each of these innovations, when designed well and conducted by well trained faculty and staff, result in increased achievement on program goals, increased satisfaction by students (and faculty) regarding the program and its effectiveness, and increased retention in STEM subject-matter (note that retention is sometimes defined as taking future courses, and so is not adequately operationalized).[11]

Table 1: Evidence-based Practices in Engineering that are in Place in the Studied Institution

Evidence-based Practices	**Impact**
Co-Curricular Experiences	
• *Undergraduate Research* o Undergrad Research Initiative o EPICS (Engineering Problems in Community Service) o Grants in REU (Research Experience for Undergraduates) • E2 Freshman Camps • Professional Societies	• Increased engagement of undergraduates in research with faculty • Relationships between students and faculty in engineering and across departments • Student retention and satisfaction • Helps develop disciplinary professional identity
Course/Curricular Experiences	
• Student Success Course • Introduction to Engineering	• Increased contact (relationships) with faculty • Student success skills • Engineering design content • Team work • Engagement in deep project-based learning on engineering design challenges • Student retention and satisfaction
Student Support Programs	
• Learning Assistants (Peer Mentors) • Undergraduate TAs • Supplemental Instruction • Student Residential Communities	• Peer mentor is a role model of successful engr. student • Identification with Program • Student success

Purpose of This Paper

This paper reports on the relationships among key factors in faculty attitudes and practices, connections among faculty within and across departments, and key course-level predictors of persistence in Engineering. We focus on freshman courses and faculty teaching those courses in the School of Engineering, and in the Physics, Chemistry, and Mathematics departments.

Method

Institutional Context

The School of Engineering in the studied University serves approximately 6,000 undergraduate students each year. A recent study (2007) of persistence rates of engineering majors across required STEM coursework revealed that 43% failed to persist from first semester Calculus to second semester Calculus, 33% failed to persist following 2nd semester Calculus, and 32% stopped after their third semester. Consequently about 1/3 of students dropped out of mathematically intensive majors by 2 courses into their program and consequently switched to a non-STEM major. These findings are echoed in required Chemistry and Physics courses: Chemistry - 41% of engineering majors do not take the next Chemistry course after the 1st semester; and for Physics - between 36% and 65% of engineering majors drop after 1st semester

Physics. In addition to these numbers, the percentage of students in these courses receiving grades of D, F, or W (withdraw) ranges from 25% to 40%. Clearly more students are not persisting than would be predicted by grades alone. Something else must be causing engineering students to stop taking advanced STEM coursework.

Student Support Initiative

Beginning in the late 1990s the School of Engineering instituted a concerted initiative to curtail attrition of its engineering students. In addition, in 2003, graduation requirements for its programs were reduced from 128 credit hours to 120 credit hours by state mandate. This afforded students a reduced workload and more flexibility in their scheduling, making it more feasible for them to graduate within the standard 4-, 5-, or 6-year tracks. Rates of persistence in Engineering grew both as a result of the initial support initiative, and as a result of the credit reduction. However, the rate of change was marginal (~1% per year).

Starting in 2007, a more targeted effort was established, focusing on the freshman and first two years' experiences for all engineering majors. Prior to 2007, most reforms implemented focused on programs and curriculum. In 2007, focus was shifted to supporting the belongingness needs of students. In brief, the initiative developed support programs focusing on *Co-Curricular Experiences*, *Course Curricular Experiences*, and *Student Support Programs*.

> *Co-Curricular Experiences* include undergraduate research opportunities, engineering summer camps for freshmen, and professional student societies (often specific to a student's major). The intent of these programs is for students to be able to bond with one another and with faculty outside of the classroom, all the while honing their research and professional skills.
>
> *Course Curricular Experiences* refer to two mandatory courses all engineering students must take. The first is a student success course taken by all entering university students focused on time-management and study skills. The second is a revised introduction to engineering course designed for first-year students, geared toward problem-solving and team-building tasks.
>
> *Student Support Programs* are many-fold and include upper-division engineering students serving as peer mentors and undergraduate teaching assistants (UGTAs), supplemental instruction made available through an engineering-specific tutoring center, and a student residential community wherein all freshmen engineers live together in a centralized, on-campus complex. Together these policies provide both support and role models for students who may be struggling while also promoting the development of close-knit, supportive cohorts within the greater engineering community.

To test the hypothesis that the reforms initiated in 2007 significantly improved student persistence when compared to previous efforts, an interrupted time-series analysis was performed, regressing 2-year persistence for the freshman cohorts spanning 1998 through 2006, and then from 2007 through 2011. Under this model, significant increase in the slope of the regression line predicting 2-year persistence serves as evidence of initiative effectiveness.

Participants

Instructors

Twenty-one instructors across nine STEM departments were solicited for the study. Faculty were distributed by department thusly: 13 Engineering (4 Biomedical Engineering, 1 Mechanical/Aerospace, 2 Electrical Engineering, 2 Freshman Engineering, 1 Materials Science, 1 Computer Systems, and 2 Civil), 4 Physics, 2 Mathematics, and 2 Chemistry. All instructors teach at a large, urban, Southwestern University in the United States. Faculty participants were randomly selected from the list of faculty in each department teaching required STEM courses for freshman engineering students. Faculty were provided small stipends as compensation for their time.

Students

Data consisted of the institutional records of 615 first-time, full-time freshmen engineering students enrolled at a major University in the Southwest United States in the academic 2007 calendar year. Additional data was collected for cohorts ranging from 1998 to 2011 to assess two-year persistence patterns.

While the data reported in this paper records student persistence from Summer/Fall 2007 through Fall 2013, it is important to note that enrollment has grown precipitously over the past 7 or 8 years; from approximately 650 full-time freshmen in 2007 to 1,500 in 2012. Fall, 2014 recorded 2,500 first time-full-time Freshmen. This has changed the characteristics of the student body in important ways. Table 1 shows overall undergraduate engineering enrollment by ethnicity. Asian, Hispanic, Pacific Islander, and Nonresident Alien ethnic group populations have grown proportionally compared from 2007 to 2012. The proportion of Hispanic students is significantly higher, the proportion of African Americans have remained the same, while Whites and American Indians have dropped proportionally.

Gender ratio changed only slightly in that time period: Women represented 17% of the overall engineering student body in 2007 compared to 18% in 2012 (See Table 2).

Table 2. Undergraduate Enrollment Ira A. Fulton Schools of Engineering 2007

	American Indian	Asian	African American	Hispanic	Pacific Islander	White	Nonresident Alien	Total
2007	112 (2%)	417 (7%)	148 (2%)	621 (10%)	0 (0%)	3,140 (50%)	1,480 (23%)	6,343
2012	96 (1%)	717 (8%)	186 (2%)	1,167 (13%)	10 (<1%)	4,096 (47%)	2,186 (25%)	8,775

Interviews

Each faculty member in the study participated in one one-hour semi-structured interview focusing on teaching practices, teaching resources used, teaching environment, course and departmental policies, self and departmental evaluations, and departmental and interdepartmental collaboration.

Approaches to Teaching Inventory (ATI)

A twenty-two item revised version of the Approaches to Teaching Inventory (ATI) was used to assess faculty perceptions about their own teaching[12]. Items on the ATI fall into four dimensions: 1) Conceptual Change Intention, measuring the degree to which instructors are aware of, and support development of student understanding in the class (e.g., I see teaching as helping students develop new ways of thinking in this subject); 2) Student-Centered Strategies, measuring the extent to which instructors utilize pedagogical strategies that focus on student learning (Teaching in this subject should help students question their own understanding of the subject matter); 3) Information Transmission, the extent to which the instructor emphasizes getting information to the student (e.g., I think an important reason for running teaching sessions in this subject is to give students a good set of notes); and 4) Teacher-Focused Strategies (e.g., My teaching in this subject focuses on delivering what I know to the students). The first two dimensions promote Student-Centered classroom practice, while the latter two promote Teacher-centered classroom practice. Reliabilities of the subscales range from alpha = .73 to .75. All instructors completed the ATI in one half-hour sitting.

Classroom Observations:

Each course section was observed three times, yielding a total of 63 observations. The Reformed Teaching Observation Protocol (RTOP) was utilized to identify teaching practices associated with reformed teaching (heavily weighted towards Learner-Centered practices. The RTOP is a 25-item classroom observational protocol showing high reliability and validity[13]. Published reliabilities of RTOP subscales are: Lesson Design and Implementation (alpha = .915), Propositional Knowledge (alpha = .670), Procedural Knowledge (alpha = .946), Communicative Interactions (alpha = .907), and Student/Teacher Relationships (alpha = .872). The overall RTOP has a reliability of alpha =.954. RTOP scores for each participant's three observations were averaged to gain a typical view of their practice, resulting in a single set of scale scores for each participant. Ethnographic field notes were also gathered to assess class environment, linguistic and communal practices, and student actions/reactions to instructor moves.

Impact of Mathematics Courses

To test the hypothesis that the courses in which students initially enroll predict subsequent persistence in engineering, we tracked the 2007 cohort and their persistence to graduation as a function of their first year math course level and the grade they received in their first mathematics course. These students' first year courses were broken down by course type (Physics, Chemistry, Mathematics, and First-Year Engineering). Non-significant effects were found for Physics, Chemistry and First-Year Engineering for this cohort, so we report only results for Math courses.

To assess level of first year math course, students were divided into three groups: 1) students who took Calculus I for their first math course; 2) students that took a course considered above Calculus I for their first math course; and 3) students that took a course below Calculus I (typically Pre-calculus).

To assess the effect of grades in these courses, we divided students into three groups within course: 1) Students who excelled (Received either an A or B grade); 2) Students who passed but didn't excel (Received a C grade); and 3) Students who performed poorly (Received a D or F grade). This student cohort was then tracked to ascertain their persistence over 6 years.

Results

To assess the impact of the overall student support efforts, a form of interrupted time series, utilizing regression discontinuity analysis was performed (See Figures 2, 3, and 4). Two-year retention rate was regressed on year beginning with the 1998 cohort. Overall, student retention improved at an average rate of 1.1 percent per year (Figure 2). If, however, the time period prior to 2007, the year in which the new wave of reforms were instituted, the improvement rate is only .9 per year (Figure 3). Following the addition of the new strategies, however, the average rate of increase in retention then jumps to 1.6 percent per year (Figure 4), an improvement of about 88%. Coupled with the fact that the incoming freshman class increased from an average of 774 to 957 students over this period, the new strategies appear to be successful in helping to retain a growing percentage of a growing number of students.

Figure 2: 2-year Persistence of Engineering Freshmen, overall, 1998 cohort through 2011 cohort

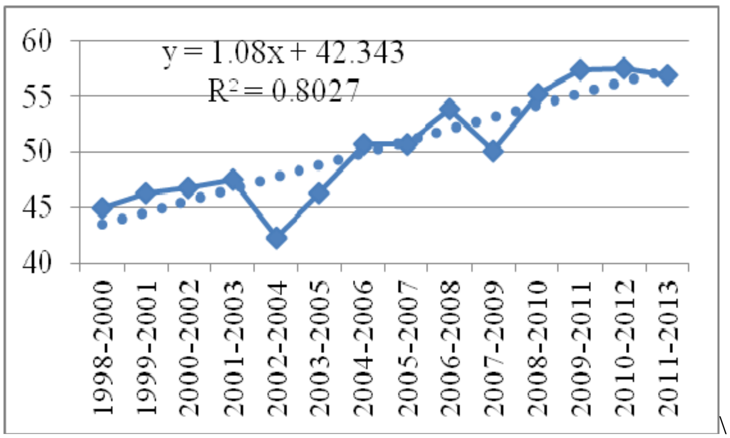


Figure 3: 2-year Persistence of Engineering Freshmen, overall, 1998 cohort through 2006 cohort

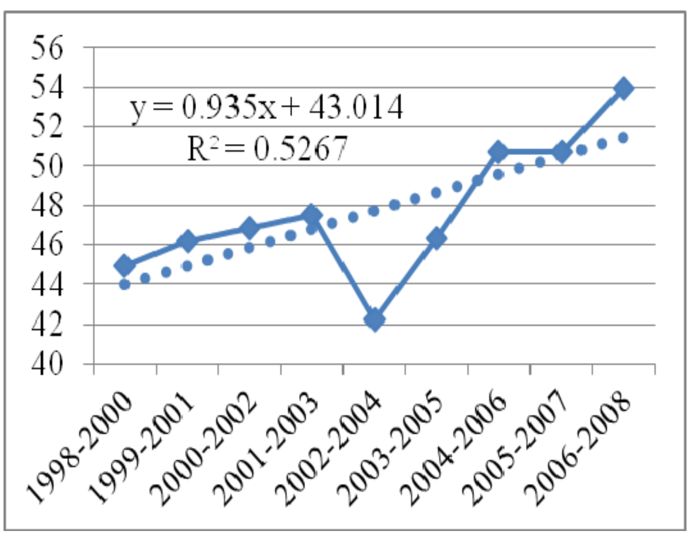
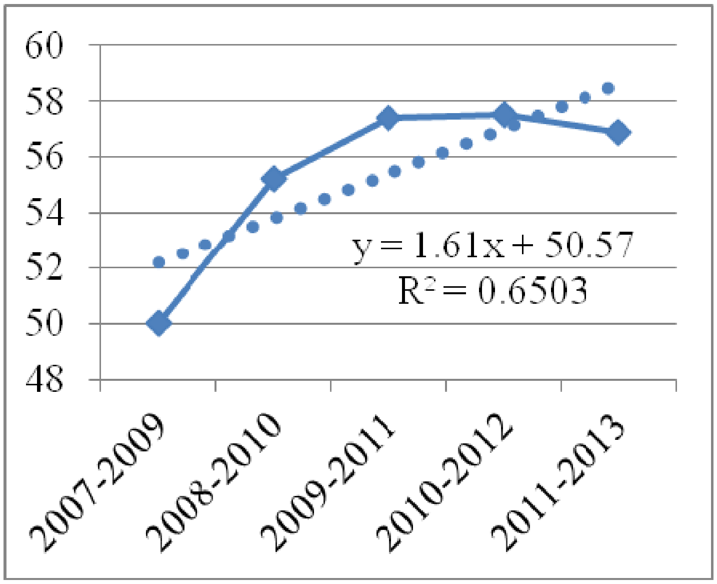


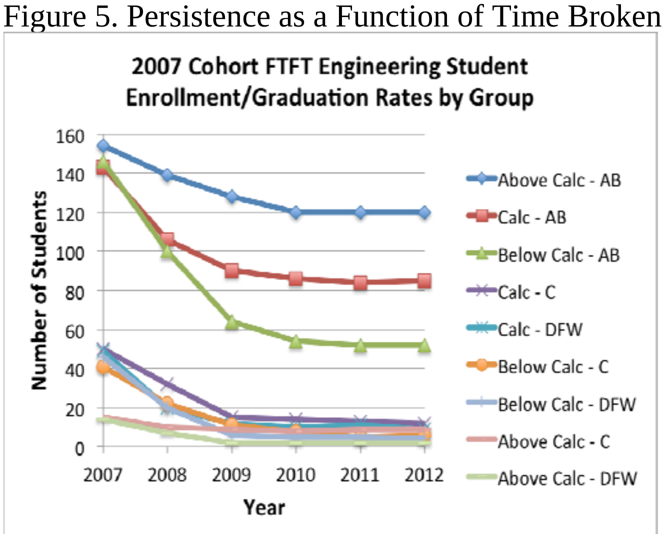
Figure 4: 2-year Persistence of Engineering Freshmen, overall, 2007 cohort through 2011 cohort



The Role of Mathematics in (non) Persistence

Fig. 5 plots the number of persisters, grouped by course level and grade, as a function of the time (years) enrolled/graduated after their first mathematics class. It is clear at a glance that the first 2 years in engineering show the largest drop in persistence rates for all nine groups. After the first three years, the persistence rate stabilizes across all groups.

Figure 5. Persistence as a Function of Time Broken Out by First Math Course & Grade Received



The biggest student loss in numbers clearly comes from our group of students, regardless of course, who receive As and Bs. Forty-two percent of the students who received As or Bs in their first mathematics course at ASU decided to leave engineering between 2007 and 2012. As discussed in the literature review, receiving a lower grade DOES correspond with a higher probability of leaving engineering. Three-fourths of freshmen who received Cs on their first mathematics course left engineering before graduation, and 84% with Ds, Fs, or W grades, regardless of course, left.

Table 3. First Time Engineering Freshman Tracking by Course Group

Course Group	Grade Group	Fall 2007 Enrolled	Total Loss (as of Fall, 2012)	First Enrolled Total	Total Loss	% Loss
Below Calc Calc Above Calc	**AB**	147 145 155	95 58 35	447	188	42%
Below Calc Calc Above Calc	**C**	41 50 15	35 38 6	106	79	75%
Below Calc Calc Above Calc	**DFW**	29 23 10	25 18 9	62	52	84%
Total		615	319	615	319	52%

Table 4. First Time Engineering Freshman Tracking by Grade Group

Course Group	Grade Group	Fall 2007 Enrolled	Total Loss (as of Fall, 2012)	First Enrolled Total	Total Loss	% Loss
Below Calc	AB	147	95	217	155	71%
	C	41	35			
	DFW	29	25			
Calc	AB	145	58	218	114	52%
	C	50	38			
	DFW	23	18			
Above Calc	AB	155	35	180	50	28%
	C	15	6			
	DFW	10	9			
Total		615	319	615	319	52%

Course level was also shown to be a significant predictor of student persistence, controlling for grades. Only 28% of students who took a course beyond Calculus I for their first mathematics course switched from engineering to another major or left the university altogether. This contrasts with switching rates of about half of the students who took Calculus 1 as their first course, and 71% of students that took below Calculus for their first mathematics course (see Tables 3 and 4).

A binary logistic regression with two main effects (Course and Grade) was performed to test the extent of this effect (see Table 5). This analysis regresses levels of each independent variable, on the log-odds (or "risk factors") associated with persistence, the binary outcome. Effects for both Course Level and Grade were found to be significant (chi-square value of 130.713 with a p-value < 0.001).

The Log Odds for each level of independent variable shows us that, if a student from the 2007 cohort taking a first mathematics course above Calculus 1 yields odds that are 2.3 times more likely for persistence than a student who took Calculus 1. If a student took Calculus, they were more than half again as likely to persist to graduation than if they took Pre-calculus or another course below Calculus.

Grade shows a similar effect. A student earning an A or B in their first mathematics course had odds 6.5 times higher to persist than someone who received a D, F, or W in their first mathematics course. Most importantly, if the student received *a C in their first mathematics course,* their persistence to graduation *did not statistically differ from someone who received a DFW.*

Table 5. Binary Logistic Regression Model Coefficients Predicting Persistence in Engineering by First Mathematics Course Taken and Grade Received in that Course

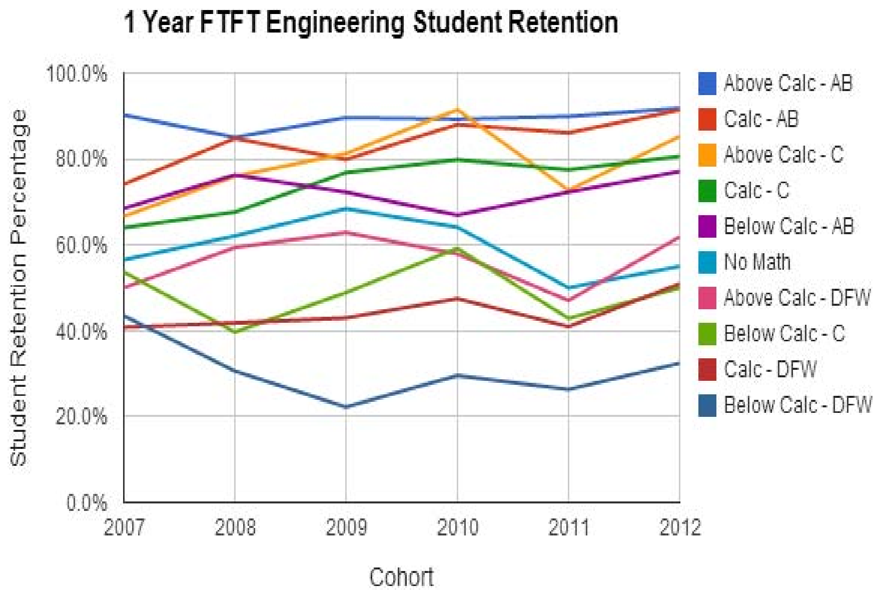
Source	B	S.E.	Wald	df	Log Odds
Calc I			57.21*	2	Ref.
Above Calc	.844	.226	13.94*	1	2.33
Below Calc	-.910	.213	18.24*	1	.40
DFW			45.88*	2	Ref.
AB	1.866	.371	25.30*	1	6.46
C	.573	.425	1.82 (NS)	1	1.77
Constant	-1.500	.372	16.29*	1	.22

*significant P<.0001

Two Year Persistence

What is also evident from our analysis (see Figure 5) is that, following the first two years, attrition from engineering as a major levels off. Only 15% of all attrition occurs after the first two seminal years. For this purpose, two-year persistence can be used as a critical measure of the success of engineering programs. Drilling down to the impact of mathematics classes on 2-year persistence (Figure 6), we can see that, following the 2007 academic year, the greatest impact on persistence has come from those that get As, Bs, or Cs in Calculus I as their first mathematics class (See Figure 5). The slope of most of the curves in Figure 5 show some random variability, but remain basically flat, with the exception of those students who take Calculus I as their first course and who earn an A or B (Red line), or C (Dark Green line). Students who enter Above Calculus and receive C also appear to have improved 2-year persistence, but their curve shows more variability.

Figure 6. 2-year Retention by Course- and Grade-level

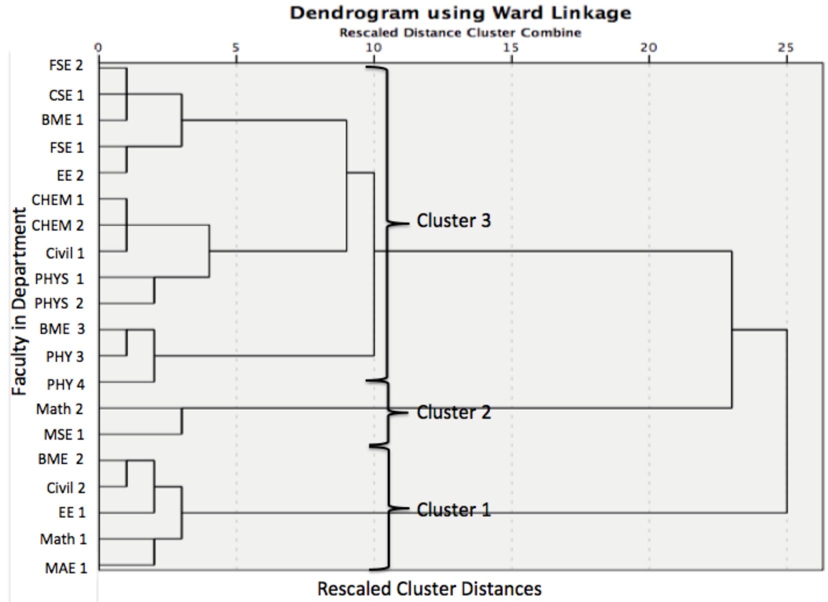


Relationship Between Faculty Attitudes and Practices

Faculty Clusters. One of the key questions to be answered in this study concerned the faculty culture to which engineering students are subjected. Similarities among faculty attitudes, beliefs, and practices within and across departments, can be considered an index of the faculty culture. To determine similarities among faculty, we performed a hierarchical cluster analysis, grouping faculty participants by similarities across their average ratings on the ATI scale.

Cluster analysis techniques examine the distances between each participant, represented as a point in a multidimensional space. Participants who are simultaneously close to each other, but farthest away from other points are considered a cluster. The algorithm for joining pairs of closely-related participants to other pairs is iterative, examining each potential pairwise combination exhaustively, then moving to larger groups of participants. A squared Euclidean distance metric was used to determine intercluster distances because ATI beliefs constructs are averages across several dimensions, approximating a continuous scale. Wards method, a technique that minimizes the variance of total intra-cluster distances was chosen to determine true cluster membership. The dendrogram presented in Figure 7 shows a clear distinction for three groups of faculty. Subjects MAE 1, Math 1, Civil 2, and EE 1 make up Cluster 1. Subjects MSE 1 and Math 2 make up Cluster 2, and the remainder of the participating faculty make up Cluster 3. Some caution must be taken here, as, due to the small sample, determining "true" clusters from error clusters is not straightforward. There may be more true groups of faculty than we have chosen, but to be conservative, we limited the number of clusters to three.

Figure 7. Faculty Clusters on ATI Dimensions

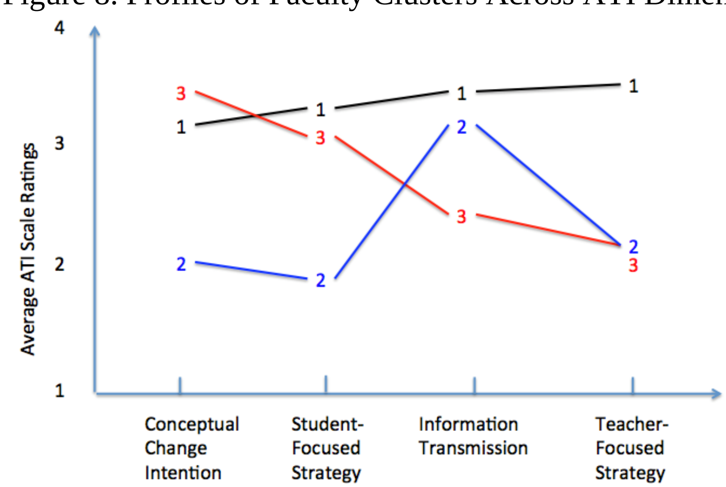


How Faculty Clusters Are Distinguished by Attitudes and Practices.

Three distinct profiles of faculty emerge from this analysis: Faculty who are more Student-centered (Cluster 3), faculty who are more Teacher-centered (Cluster 2), and a group that does not distinguish clearly among philosophically opposed dimensions of teaching (Non-discriminating, Cluster 1).

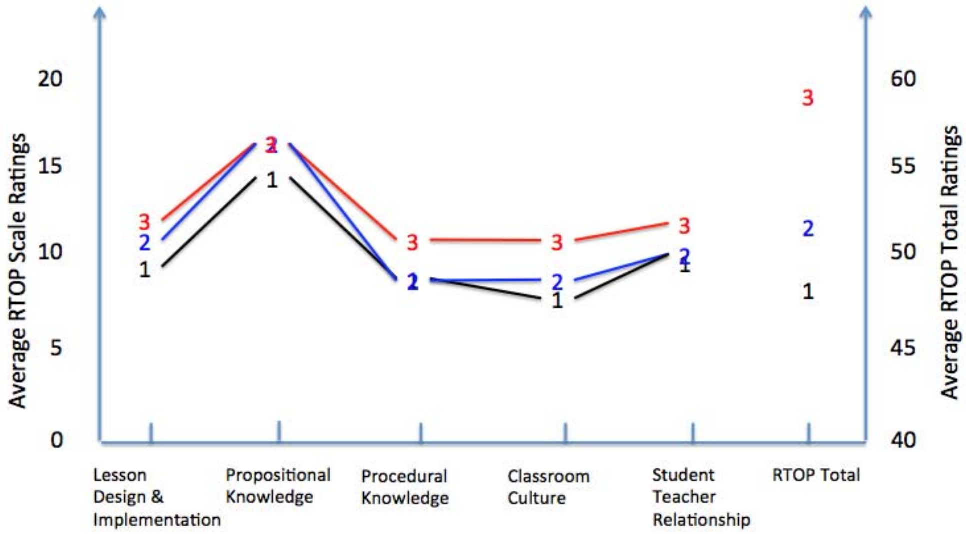
Plotting the profiles of faculty clusters across ATI dimensions, we see clearly different attitudes distinguish the three groups (See Figure 8). Importantly, faculty seem to cluster around their departmental peers. All four participating physics instructors, for example, appear in Cluster 3. Both Chemistry professors, both freshman engineering professors, and 2 of the three Biomedical Engineering professors show similar profiles of attitudes towards Student-Centered instruction.

Figure 8. Profiles of Faculty Clusters Across ATI Dimensions



Faculty clusters were then used as comparison groups, to determine if they differ significantly in teaching practice. Overall, faculty in Cluster 3 (Student-centered faculty) had higher RTOP scores from observation of their practice, across all dimensions, than either Teacher-centered faculty or non-discriminating faculty. Effect sizes for total RTOP scores were .71 between Student-centered faculty and non-discriminating faculty, and .58 between Student-centered and Teacher-centered faculty. When examined for each RTOP dimension separately, the dimensions of classroom culture, and student-teacher relationships contributed the largest differences for Student-centered faculty (see Figure 9).

Figure 9. Profiles of Faculty Clusters across RTOP Dimensions



We found considerable variability across departments, and even within departments (BME, for example), in the quality of instructional practices. Numbers are very small, and so we are hesitant to report that these are systematic indicators of faculty attitudes and practices for each department (see Table 7). At best, we can see that Freshman Engineering instructors showed a clear Student-centered orientation to both attitudes and practices, while . Mathematics, showed a definitively Teacher-centered attitude.

Table 6. Mean ATI Scale Scores by Department

Department		Conceptual Change Intention	Student-focused Strategies	Information Transmission	Teacher-focused Strategies	CCSF	ITTF
Math	Mean	2.65	2.35	3.30	3.20	2.39	3.27
	SD	.21	1.34	.00000	.85	.86	.38
Freshman Engineering	Mean	3.8	3.15	2.5	2.6	3.33	2.5
	SD	.00	.21	.28	.57	.16	1.3
Chemistry	Mean	3.15	2.80	2.75	2.70	2.83	1.91
	SD	.21	.14	.07	.14	.08	.13
Physics	Mean	3.03	2.70	1.63	2.25	2.83	1.91
	SD	.46	.85	.22	.72	.56	.40

Biomedical Engineering	Mean SD	3.20 .17	3.30 .30	2.47 .76	2.60 .69	2.42 1.6	1.91 1.4
Mechanical/ Aerospace	Mean SD	3.50 .	3.70 .	4.00 .	4.00 .	3.56 .	4.00 .
Electrical Engineering	Mean SD	4.00 .00	3.70 .00	2.95 .35	2.80 .85	3.78 0.00	2.86 .58
Computer Systems	Mean SD	4.00 .	3.60 .	2.30 .	2.80 .	3.67 .	2.55 .
Materials Science	Mean SD	1.30 .	1.90 .	3.20 .	1.80 .	1.33 .	2.55 .
Civil Engineering	Mean SD	3.40 .57	3.00 .14	2.95 1.06	2.90 .14	3.00 .31	2.91 .51
Total	**Mean** N SD	**3.23** 20 .66	**3.00** 20 .68	**2.62** 20 .74	**2.69** 20 .66	**2.87** 20 .91	**2.52** 20 .84

Discussion and Conclusions

Results of project so far suggests that long-term efforts put forth by the Schools of Engineering is resulting in improving student persistence. Implementation of the instituted reforms is uneven across departments, particularly when math is taken into account. Freshman math experiences, in particular, are shown to be negatively related to student persistence to graduation in an engineering major, and a chief culprit for this relationship appears to be a Teacher-centered, Information-transmission attitude and practices among mathematics faculty. This is certainly not the only causal factor for students choosing to leave Engineering as their chosen profession, but the odds-ratios we uncovered in this study point to a significant partial cause.

More specifically, our analysis provides evidence that entering into Engineering at a below Calculus level, at the studied institution, is almost a death-knell for aspiring students. The probability of successfully graduating in Engineering for these students is around 30%, while students who begin their Engineering experiences at Calculus or above have a 50% to 75% probability of graduating in their chosen major, respectively.

Grades were also shown to be a significant factor. Cabrera, Amaury, and Castaneda[5] that demonstrated that GPA is the most important academic determinant of students' intention to persist in University. Our work echoes their findings, showing that grades in the very first mathematics course a student takes in Engineering, determines the student will successfully graduate 4 to six years later. Curricularly, performing below a C level in Calculus or taking a below Calculus offering automatically prevents students from enrolling in further engineering coursework their second semester at the University. Thus, grades likely serve as a gut-check for students who may be unsure of their career intentions, or who may feel trepidation at their own skill level relative to their engineering aspirations. Lower than expected performance may be used by students, as an indicator that engineering is not for them[4,14].

Overall, results of the project to date indicate that there is a strong need for faculty professional development to shift pedagogy more toward student-centered learning. In addition, entering students need to be calculus ready and the students would likely benefit from more effective teaching in early math courses, focusing more on Student-centered practices. Finally, student support activities appear to be effective in improving students' sense of belongingness as well as helping develop students' engineering professional identity, thus resulting in improved persistence to graduation.

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