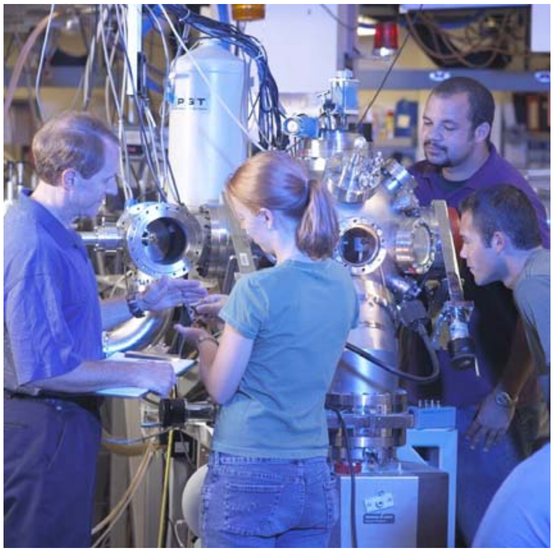

—FAILING THE FUTURE—

PROBLEMS OF PERSISTENCE AND RETENTION IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) MAJORS AT ARIZONA STATE UNIVERSITY

ASU Freshman STEM Improvement Committee

Submitted to Executive Vice President & University Provost Elizabeth Capaldi

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FAILING THE FUTURE: PROBLEMS OF PERSISTENCE AND RETENTION IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) MAJORS AT ARIZONA STATE UNIVERSITY

Report Prepared & Submitted by the
Provost's Freshman STEM Improvement Committee

Patrick W. Thompson, Mathematics & Statistics (Chair)

Carlos Castillo-Chavez, Mathematics & Statistics

Robert J. Culbertson, Physics

Alfinio Flores, Curriculum and Instruction

Ronald Greeley, Earth and Space Exploration

Susan Haag, Engineering

Anton E. Lawson, Life Sciences

Seth D. Rose, Chemistry & Biochemistry

Ronald L. Rutowski, Life Sciences

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1. EXECUTIVE SUMMARY

Arizona State University joins other institutions of higher education nationwide in being alarmed and puzzled by the large numbers of students who come to campus with the declared intention of becoming engineers, mathematicians, or scientists, but drop their majors after taking one or two freshman courses. The cost of this loss to a nation and state hungry for technically talented workers is incalculable. Leaders in government and industry are pushing colleges and universities to understand the problem and to do better.

Thus, over the past year, a multidisciplinary faculty committee has been gathering and analyzing data to document, understand, and recommend possible solutions to persistent problems in Arizona State University's freshman programs in science, technology, engineering, and mathematics (STEM). This report culminates the committee's work.

Former ASU Provost Milton Glick issued the original charge to the committee. Current Executive Vice President and University Provost Elizabeth Capaldi confirmed the committee's charge in September 2006.

Specifically, provosts Glick and Capaldi charged the committee to:

- Ascertain the facts relative to the experience of students in ASU's introductory courses in mathematics, engineering, and the sciences
- Derive from these facts a portrait of the current condition of freshman STEM courses at ASU that includes both qualitative data (such as student attitudes and beliefs about STEM subjects) and quantitative data (such as course pass/fail rates)
- Discern and describe the probable causes for high rates of failure and related problems in ASU's freshman STEM courses
- Identify strategies, practices, and programs, and evidence for their success, that other universities nationwide have used to improve outcomes in first-year STEM courses
- Propose a plan of action whereby ASU can become among the top 10 universities in the nation in the success rates of freshman courses in mathematics, engineering, and the sciences

The committee gathered quantitative and qualitative data to ascertain 1) the facts about ASU students' persistence in STEM majors and 2) the reasons students cite for deciding to abandon their ambitions to major in a STEM discipline.

In analyzing student persistence in the majors targeted by the study, the committee used an innovative indicator: **The rate at which students in a major succeed in (get credit for) the next course in a sequence that is required by that major.**

The committee examined the rates at which students in the principal STEM majors (engineering, mathematics, physical sciences, life sciences, and technology majors such as computer science) got credit for the next course in a sequence in the subjects most often required in STEM majors (calculus, biology, chemistry, physics).

For example: An engineering student whose major requires MAT 270 and MAT 271 is a “persister” if she gets credit for 271 and a STEM “drop-out” if she does not get credit for 271 within two years of completing 270.

By this measure, every semester ASU is losing high rates of majors in every STEM discipline. These are not just under-prepared students, but many of the better ones. It was chilling to the committee to learn that:

> **Forty-three percent of students who receive an A in precalculus and who had declared a STEM major that requires calculus chose not to take calculus. In other words, even the very best students in precalculus who thought they wanted to enter a STEM major are leaving STEM.**

In all subjects most often required in STEM majors, the committee found relatively low persistence rates to a required second or third course. For example:

- Biology, calculus, chemistry (113), and physics (111) retain just over half their students between their first and second courses

- Calculus retains a little more than half of its students between its second and third course (for an overall persistence of approximately 30%)

- Chemistry 117 and physics 121 retain about 2/3 of their students between their first and second courses

- Among students whose current majors require two or three semesters of calculus and who took MAT 270 prior to spring 2006, 41% of them have not completed their calculus requirement and by implication have dropped from ASU

Another way to slice the data is to examine the percentage of students in specific majors who have enrolled in a second required calculus course: During the period fall 2001 through fall 2006, 43% of engineering majors, 54% of mathematics majors, 51% of physical science majors, and 50% of technology majors who enrolled in MAT 270, and whose majors required MAT 271, did not persist in MAT 271.

Something in the experiences students have in their early STEM courses at ASU causes them to switch majors or drop out of the university. In seeking to identify causes, the committee was guided by the national research literature in constructing a survey that was administered to 862 students who, according to ASU Data Warehouse, switched from a STEM major to a non-STEM major during their freshman year.

In summary, the 345 responders to the survey reported that they were more satisfied with the student and classroom cultures in their new majors than they had been in their STEM majors. They found faculty in their new majors easier to approach and, from students' perspectives, to provide higher-quality instruction. They found better advising and counseling in their new majors. And their grades improved markedly in their new majors.

Only in engineering did students report that they felt academically unprepared for a STEM major in their first courses. In no major did students point to financial difficulty as a reason for switching majors, nor was workload or pace of instruction a particular concern.

Again guided by the national research literature, the committee employed the Reformed Teaching Observation Protocol (RTOP) to examine the nature of the instruction ASU's freshman STEM courses are offering to students. Observations were arranged for courses in introductory biology, chemistry, and physics. The Department of Mathematics and Statistics, with the support of Dean Sid Bacon, declined to allow observations of calculus instruction. In all, 12 instructors participated.

The committee found that freshman STEM instruction tends to be instructor-centered, procedural (rather than conceptual) forms of instruction that have been called into question by research into human teaching and learning. The committee examined assessments used in STEM courses and found them similarly out of sync with best practices recommended in the research literature.

The committee acknowledges that many ASU students arrive under-prepared for the rigors of college study. But neither that, nor the oft-expressed need to "cover the material," can excuse faculty from employing well-researched methods available to teach the students they get rather than they students they wish they had.

In its study of best practices, the committee found strong examples in the University of Buffalo's strategy for addressing low engineering persistence rates, SUNY Potsdam's approach to recruiting and retaining undergraduate mathematics majors, and the University of Arizona's strategy to improve its undergraduate mathematics programs.

In summary, the committee sees the overall problem of retention in STEM majors as being one of culture and environment. This overall problem, in turn, entails issues of curriculum, instruction, and institutional support.

There are particularly stubborn issues in ASU's mathematics programs. The committee finds it highly problematic that the tenured mathematics faculty has so little stake in lower division mathematics programs and instruction. The department's refusal to participate in the committee's teaching observations was troubling.

The committee believes that the most difficult aspect of improving the university's outcomes in freshman STEM programs may lie in first **acknowledging the size of the challenge we face.**

The committee recommends reforms that span the spectrum of the university's operations—from faculty's conception of what "good teaching" means to the university's systems for evaluating faculty performance to ASU's engagement with K-12 practice and the Arizona Department of Education.

The committee offers 11 specific recommendations to the provost for improving ASU's freshman STEM programs. In brief:

1. Require each STEM department to engage in a process of self-study that considers the contents of this report and results in a plan for improving student persistence and retention

2. Establish an interdepartmental STEM coordinating committee and a provost-level undergraduate STEM advisory committee

3. Establish a system that rewards departments for high persistence rates and high retention rates

4. Establish a system that rewards instructors of entry-level courses for adopting and modeling student-centered methods of instruction as measured by RTOP and for achieving high persistence rates among their students from one course to the next. Create a virtual college for tenure-track faculty who have declared a scholarship of teaching as their primary emphasis

5. Establish an evaluation-of-instruction system that goes beyond end-of-semester student questionnaires. RTOP would be highly useful in evaluating instruction

6. Encourage departments to draw on the expertise of their mathematics education or science education faculty in improving introductory instruction and curricula

7. Encourage departments to adopt and use learner-centered pedagogy as promoted by ABOR

8. Provide workshops for instructors, teaching assistants, and faculty that address issues of scientific teaching and best practice in STEM pedagogy, and expand opportunities for undergraduates to participate in research mentored by a faculty member

9. To address special problems in precalculus and calculus, create an oversight committee composed of representatives from departments whose students take calculus to advise the Mathematics Department on their students' needs. Encourage the Mathematics Department to draw on the expertise of its mathematics education group and its award-winning mathematics faculty to improve calculus and precalculus instruction

10. Convene all ASU advisors engaged in counseling students in the STEM disciplines to prepare a report for Provost Capaldi and college deans that assesses the current condition of STEM advisement and recommends improvements

11. Form a university committee that will recommend to the provost and the president strategies by which ASU can exert leadership in the mathematical and scientific preparation of Arizona school students

2. RATIONALE FOR COMMITTEE

In every corner of U.S. society from academia to industry, government, and the media, there is virtual unanimity that the shortcomings of American education in the STEM disciplines pose alarming threats to the nation's future.

The United States is graduating too few engineers to innovate on the frontiers of new technologies, too few scientists to discover the fundamental knowledge that enables new technologies, and too few mathematicians to model the algorithms that make innovation and discovery possible.

In Arizona, concern that an underperforming STEM education system will affect the state's ambition to emerge as an international hub for knowledge-intensive innovation may have reached a tipping point.

As chair of the National Governors Association, Arizona Governor Janet Napolitano has made reform of STEM education a central thrust of the "Innovation America" theme she has chosen to motivate her tenure. The Arizona business community has pledged to invest political and economic capital in improving the STEM education system on which high-technology companies depend for their workforce. Arizona State University President Michael Crow, in launching the Arizona Initiative in Mathematics and Science Education (AZIMASE), placed STEM education at the center of ASU's vision for the New American University.

Yet Arizona State University, like other institutions nationwide, has exhibited indicators of serious problems in its programs of education in the STEM disciplines, particularly in introductory courses and in the areas of student persistence and retention.

In light of these concerns, in February 2006 Provost Milton Glick formed the Freshman STEM Improvement Committee (FSIC) to investigate the state of STEM education and to make recommendations for improving it.

Specifically, Provost Glick charged the committee to:

- Ascertain the facts relative to the experience of students in ASU's introductory courses in mathematics, engineering, and the sciences
- Derive from these facts a portrait of the current condition of freshman STEM courses at ASU that includes both qualitative data (such as student attitudes and beliefs about STEM subjects) and quantitative data (such as course pass/fail rates)
- Discern and describe the probable causes for high rates of failure and related problems in ASU's freshman STEM courses

- Identify strategies, practices, and programs, and evidence for their success, that other universities nationwide have used to improve outcomes in first-year STEM courses
- Propose a plan of action whereby ASU can become among the top 10 universities in the nation in the success rates of freshman courses in mathematics, engineering, and the sciences

Provost Elizabeth Capaldi reaffirmed ASU's commitment to STEM education and in September 2006 asked the committee to continue its work.

In response to the provost's charge, the committee collected and examined data on:

- Persistence in introductory STEM courses that are required by students' majors
- Nature of course instruction as measured by the Reformed Teaching Observation Protocol (RTOP)
- Nature of course examinations (according to Bloom's taxonomy of educational objectives)
- Sizes of course sections
- Students' academic preparation as measured by SAT
- Students' feelings and opinions about their STEM courses and about their preparation for them
- Instructors' and administrators' thoughts on the problems the committee found
- Students' stated reasons for deciding not to continue in a STEM major

2.2 Definition of "Persistence" in STEM Majors[1]

How one defines persistence dramatically influences the picture one gets of the number and proportion of students who continue in a STEM major. A large literature on student persistence in university programs defines persistence as the rate at which students continue to the next year at the university or in their programs (Sabharwal, 2005).

The committee examined data relating to next-year continuance, but also sharpened the focus to include a definition of persistence that is more telling for understanding attrition in STEM majors. That definition of persistence is:

[1] Appendix I lists all majors included as STEM majors. The major of every student who enrolled in BIO 187-188, CHM 113-115/116, CHM 117-118, MAT 270-272, PHY 111-112, or PHY 121-131 at any time from Spring 2001 to Spring 2006 was categorized as within a STEM area or as not STEM.

The rate at which students in a major succeed in (get credit for) the next course in a sequence that is required by that major.

The committee elected to add this definition to the analysis because next-year continuance tells us only that students continue to enroll in ASU classes. It does not capture whether students persist in a chosen major, nor does it capture at what point in their majors they cease to persist.[2] The committee decided that a focus on persistence in required introductory course sequences would provide the most useful possible feedback to departments and to the provost about how well ASU is succeeding in retaining students in STEM majors.

2.3 Methodology

For determining persistence: The committee gathered data on students' enrollment in required course sequences from fall semester 2001 to spring semester 2007. We included those disciplines that generate required course sequences in a variety of STEM majors: calculus, biology, chemistry, and physics.[3] We used a spring 2006 cutoff for *initial* courses in a sequence to assure that students would complete their sequences, were they intending to do so, by the end date of our study period (May 15, 2007).

The pool of students we analyzed comprised all students who took introductory courses in calculus, biology, chemistry, or physics. For students in each of those STEM majors, we determined what introductory sequence of calculus, biology, chemistry, and physics courses (if any) their majors require. Then we determined how many of those students who took a first required course went on to take the second or the third. Students who persist to subsequent courses in a required sequence are identified as persisting in their STEM majors. Those who do not take the subsequent courses are presumed to have abandoned their STEM majors. The committee acquired all data for its persistence study through queries to the ASU Data Warehouse.

For exploring why students leave STEM majors: The provost's charge to the committee asked that beyond drawing a statistical portrait of STEM retention at ASU, we ascertain what reasons students have for dropping out of STEM majors after taking one or two courses. What is it in their initial experiences that makes them want to leave the STEM disciplines?

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[2] Appendix I provides precise definitions of the variables used by the Committee to analyze its data.

[3] We did not collect data on students' coursework in Engineering because the College of Engineering revamped its introductory courses as of Fall 2006. The Committee felt that the current programs are so different from what they had been that past data had little to suggest about the success of these changes.

To gather this qualitative data the committee employed four instruments: a survey of STEM-leavers, analysis of classroom instruction in core STEM subjects (except mathematics), analysis of course examinations, and analysis of the mathematical preparation students bring to the university from high school. We explain our qualitative methods fully in Section 4. Suffice it to say now that in writing items for the survey and in electing to analyze instruction, examinations, and mathematical preparation, the committee was homing in on factors that the best available research suggests are chiefly responsible for students' decisions to leave the STEM disciplines.

In the following sections, we build a picture of STEM retention at ASU by summarizing the persistence data for each of calculus, biology, chemistry, and physics. We begin with calculus because it is prerequisite to most other STEM majors.

3. STATE OF FRESHMAN STEM RETENTION AT ASU

3.1 Calculus

Calculus is central to other STEM disciplines because of its power in modeling quantitative aspects of dynamic phenomena and relationships among them. Many STEM majors require one, two, or three semesters of calculus. STEM students must fulfill their calculus requirements to succeed in their majors.

The committee examined course records for all students taking the initial calculus course (MAT 270) between fall 2001 and spring 2006, inclusive. Table 1 shows that during the period fall 2001 through fall 2006, 43% of engineering majors, 54% of mathematics majors, 51% of physical science majors, and 50% of technology majors who enrolled in MAT 270, and whose majors required MAT 271, did not persist in MAT 271.[4]

The low persistence rates in Table 1 *do not* reflect a high failure rate in MAT 270. The grade distributions in MAT 270 (Table 2) show a relatively low failure rate. Almost 74% of students taking MAT 270 received a C or higher.

Persistence rates are surprisingly low even among students who received at least a C in MAT 270 and whose majors required MAT 271 (Table 3). For example, over 44% of mathematics students who received at least a C in MAT 270 either decided not to take 271 or received less than a passing grade in 271. Overall, almost one-third of all students who got at least a C in MAT 270 and whose majors required MAT 271 did not persist in MAT 271. It is worth mentioning that 663 of the 779 students who received at least a C in MAT 270—and whose majors required MAT 271—did not enroll in MAT 271.

Advanced Placement and Transfer Students

Many STEM students enter ASU with Advanced Placement (AP) credit or transfer credit and therefore begin their calculus sequence with MAT 271 or MAT 272. These students generally have better mathematical preparation than students who begin in MAT 270. We therefore expected persistence rates from MAT 271 to MAT 272 to be significantly higher than from MAT 270 to MAT 271. They were indeed higher, but persistence rates from MAT 271 to MAT 272 still averaged just under 57% (Table 5). Of students we thought should have persisted (i.e., students getting a C or better in MAT 271 and whose majors required MAT 272), over 30% did not persist in MAT 272 (Table 6).

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[4] The phrases “dropped” and “did not persist” mean that a student received a grade in MAT 270 and did not enroll in, withdrew from, or received an E (if a non-math major) or a D (if a math major) in MAT 271. We used students’ latest data, so if they re-enrolled in a course and received a higher grade, we used the higher grade in that student’s record.

We focused also on the 1244 students who entered ASU with AP or transfer credit and therefore began calculus with MAT 271. Of these students, 835 had majors that required MAT 272. Approximately 33% of students having AP or transfer credit for MAT 270, who began with MAT 271, and who were required by their major to take MAT 272, did not persist in MAT 272 (Table 7). Of students who entered calculus with MAT 271, whose majors required MAT 272, and who received at least a C in MAT 271, 76% persisted to MAT 272 (Table 8).

Repeating a Course

Another form of persistence is to “keep at it.” The committee examined course repeats because of the inefficiency of having students take the same course multiple times. Repeating a course is inefficient from both a student’s perspective and from the University’s perspective. Either way, taking a course multiple times wastes personal and taxpayer resources.

In regard to “staying at it,” many ASU students are very persistent. One student took MAT 270 four times, MAT 271 twice, and MAT 272 three times. Over the five-year period covered by this report, there were 8389 occurrences of a calculus seat being occupied by a student. Of these, there were 4547 occurrences of a seat being occupied by a student who had been there before (Table 8a).

Staying at ASU

A third meaning of persistence is staying enrolled at ASU. The committee examined the calculus data for ways to infer this. We assumed that if a student is in a major that requires two or more semesters of calculus and has not met that requirement by the end of spring 2007, then this student is no longer actively pursuing that major.[5] Of the 3353 students whose current majors require two or three semesters of calculus, 34% of them kept their original major but stopped pursuing it (Table 8b), which implies that they have dropped out of ASU. Similarly, 8% of students whose current STEM majors require two or three semesters of calculus switched to that major but stopped pursuing it. In total, 42% of students whose current majors require two or three semesters of calculus seem to have dropped out of ASU.

To gain insight into characteristics of ASU-leavers, the committee examined where in the calculus sequence they stopped pursuing their majors. We also examined their grades in MAT 270 and MAT 271. Students drop from ASU with similar regularity among students completing no, one, or two calculus courses (Table 8c). Relatively few STEM students who drop from ASU are in majors that require one or two semesters of calculus (Table 8d). Hence, the vast majority of

[5] We limited our search to students who took MAT 270 prior to spring 2006 and students who skipped MAT 270 but took MAT 271 prior to fall 2006. They would then have had three semesters to complete their remaining one course or four semesters to complete their remaining two courses.

STEM leavers who drop from ASU are in majors that require three semesters of calculus.

With the exception of life sciences, the majority of STEM students who dropped from ASU and took MAT 270 received at least a C in MAT 270 (Tables 8e and 8f). Similarly, a majority of STEM students who dropped from ASU and took MAT 271 received at least a C in MAT 271.

These are important findings, because they say that, among STEM students, it is not just poorly performing ones who drop from ASU.

3.2 Biology

Most life science majors require BIO 187 and 188, as do the pre-medical program and bioengineering[6]. We analyzed persistence in biology in the same way that we did for calculus. Table 9 gives the overall persistence rates from BIO 187 to BIO 188. However, not all BIO 187 students were in majors that require BIO 188. Table 10 gives a clearer picture of persistence in biology. Overall, only 57% of students who enrolled in BIO 187 and whose majors required BIO 188 actually persisted in BIO 188.

To see whether the low persistence rate in biology was due to a high failure rate, we examined persistence among students who received at least a C in BIO 187 and whose majors required BIO 188 (Table 11). Only 69% of students receiving a C or higher in BIO 187 and whose majors required BIO 188 actually persisted in BIO 188.

Staying at ASU

In line with our calculus analysis, we investigated the persistence in ASU of students in biology-related majors. We assumed that if a student's current major requires BIO 188 and the student has not taken it within two years of taking BIO 187, then the student is not actively pursuing that major and hence has dropped out of ASU. Of the 1463 students whose current major requires BIO 188, 39% of them seem to have dropped out of ASU (Table 11a).

The committee did not have access to course repeat data for BIO 187/188.

3.3 Chemistry

CHM 113 and one other chemistry course are required for most life science majors and several engineering majors. Chemistry majors are required to take CHM 117 and 118 (General Chemistry for chemistry majors), although just as many chemistry majors took CHM 113/116 as took 117/118. Some majors require

[6] Actually, bioengineering requires only BIO 188, but we tracked bioengineering majors as if both courses were required because if they enrolled in BIO 187 it was certainly in preparation for BIO 188.

CHM 115 (General Chemistry with Qualitative Analysis) as the second course, others require CHM 116 (General Chemistry) as the second course. Over the period of this study, 5699 students received a grade in CHM 113, whereas only 112 students received a grade in CHM 117. The content of the two sequences is sufficiently different, however, that the committee examined persistence in the two sequences separately.

Of the 5699 students who received a grade in CHM 113, 45% continued into CHM 115 or CHM 116 (Table 12). However, only 2302 (40%) of these 5699 students were in majors that required a second chemistry course (Table 13). Of the students whose majors required a second chemistry course, 56% persisted in a second course while 44% did not.

Overall, 72% of students who received at least a C in CHM 113 persisted in CHM 115 or CHM 116 (Table 14). The overall rate, however, masks a marked difference between the persistence rates of engineering and life sciences students who received at least a C in CHM 113 (74% and 78%, respectively) and persistence rates of physical science and pre-med students who receive at least a C in CHM 113 (63% and 66%, respectively).

The overall rate at which students whose majors required CHM 118 progressed from CHM 117 to CHM 118 was 68% (Table 15). Among students receiving at least a C in CHM 117, 76% of them persisted in CHM 118 (Table 16).

Staying at ASU

The committee investigated the persistence of students in chemistry-related majors in ASU. We assumed that if a student's current major requires CHM 115/116 and the student has not taken it within two years of taking CHM 113, then the student is not actively pursuing that major and hence has dropped out of ASU. There were 1877 students whose current major requires CHM 115/116, and 84% of them persisted to fulfill their major's chemistry requirements (Table 16a). We cannot say, however, that 84% of them have persisted at ASU. We can only say that it seems that only 16% of them seem to have dropped out of ASU.

3.4 Physics

Physics is required of most physical science majors, most engineering majors, and a few life science majors. PHY 111/112 is non calculus-based physics; PHY 121/131 is calculus-based physics. Neither is designed for physics majors—they are supposed to take PHY 150. Very few physics majors take 121/131. The committee analyzed the two sequences separately because they differ greatly in content and they serve very different populations.

During the period of this study, over 1100 students took PHY 112 after having taken PHY 111 (Table 17). Only 400 were in majors that required them to do so (Table 18). Seventy-three percent of these students who were required to take

PHY 112 and who received at least a C in PHY 111 persisted to PHY 112 (Table 19).

Persistence in PHY 121/131 is given in tables 20, 21, and 22. Overall, 60% of 3623 students receiving a grade in PHY 121 took PHY 131 (Table 20). Of those 3623 students, 2724 were in majors requiring PHY 131, and 65% of them persisted in PHY 131 (Table 21). Of 2145 students whose majors required PHY 131 and who received at least a C in PHY 121, 78% persisted in PHY 131. As a side note, the committee found 32 physics majors taking PHY 121, of whom 11 also took PHY 131. These students were not counted in the persistence data.

Staying at ASU

In line with other analyses, the committee examined the persistence of students in physics-related majors in ASU (focusing only on PHY 121/131 because of the small number of students who were required to take both PHY 111 and PHY 112).

Overall, 26% of students in physics-related majors seem to have dropped out of ASU (Table 22a). We should note that the disparity between these persistence rates and the course persistence rates is because ASU persistence is determined using students' current majors while persistence rates for course sequences used students' majors at the time they enrolled in the sequence's first course. The difference is due to students switching out of or into the majors by which they were classified as persisting in a course sequence.

3.5 Summary of Persistence Analyses

The prior sections focused on calculus, biology, chemistry, and physics individually. We here present these same statistics but as an overview across areas.

All areas see relatively low persistence rates to a required second or third course (Table 23).

- Biology, calculus, chemistry (113), and physics (111) retain just over half their students between their first and second courses.
- Calculus retains a little more than half of its students between its second and third course (for an overall persistence of approximately 30%).
- Chemistry 117 and Physics 121 retain about 2/3 of their students between their first and second courses.
- Among students receiving at least a C in a course, calculus and biology retain about 2/3 of them (Table 24). Chemistry and physics retain approximately 3/4 of them.

- Among students whose current majors require two or three semesters of calculus, 41% of them have not completed their calculus requirement and by implication have dropped from ASU (Table 25).

- Among students whose majors require two semesters of biology, 39% of them appear to have dropped from ASU.

- Chemistry and physics ASU drop rates are 15% and 25%, respectively. One possible reason for the lower drop rates among Chemistry 117/118 students and Physics 121/131 students is that the chemistry and physics sequences require calculus. It seems reasonable that students who fail to persist in calculus and who intended to take CHM 117 or PHY 121 will choose another direction.

3.6 Switching Among Majors

The committee calculated persistence rates in calculus, biology, chemistry, and physics among students in the various STEM majors using students' majors at the time they enrolled in the sequence's first course. But many students changed majors while taking a sequence or after having completed it. The committee thus examined another form of persistence—staying with a major. We focus on calculus and life sciences. We include calculus because of considerable overlap among students taking it and the sequences in chemistry and physics.[7]

The committee examined the rate of switching between majors in two overlapping groups—all students and students who completed the calculus requirements of their current majors.

- There is considerable switching of majors among students who enrolled in MAT 270, although 79% of them began with and stayed with a STEM major (Table 26)

- A more detailed analysis revealed that among students who did not drop from ASU, 69% began with and stayed with a STEM major (Table 27)

- Also, while STEM gained 414 students from non-STEM majors, it lost 1056 students to non-STEM majors

- Persistence in STEM is no greater for students receiving at least a C in MAT 270 than for students overall (Table 28)

- Several majors displayed significant losses in students. Engineering started with 2056 students and ended with 1454 students (Table 29) and the 602

[7] Most life sciences majors take MAT 251, Calculus for Life Science.

students that engineering lost did not drop from ASU but went to non-engineering majors

- Similarly, physical sciences went from 329 students to 204 students. Many of these students who switched from STEM majors went to non-STEM majors. During the study period, non-STEM majors increased from 757 students to 1956 students, with the majority of these new non-STEM students coming from engineering and technology. Math went from 193 to 204 students, but only 96 of these students started and remained with mathematics

- The switching patterns were similar for students who received at least a C in MAT 270 (Table 30). Non-STEM majors went from 405 students to 1074 students, again getting the majority from engineering and technology

This suggests that not only are STEM majors losing students, they are losing many of their better students.

Table 31 gives information about switches between STEM and non-STEM majors by students enrolled in BIO 187. It is worth noting that the number of STEM majors increased by 95.

4. Why Is ASU Losing STEM Students?

ASU clearly has a problem retaining its STEM students, both from the perspective of their staying with a STEM major and from the perspective of their staying at ASU. Part of the provost's charge was to understand why this might be so. In response, the committee conducted:

- A survey of freshman STEM leavers regarding comparisons between their old and new majors
- Analyses of classroom instruction in the core STEM courses (except mathematics),
- Analyses of course examinations
- Analyses of students'mathematical preparation

4.1 Clues from the National Research Literature

In seeking hypotheses that might explain the high rates at which ASU students abandon their ambitions of earning a STEM degree, the committee examined the national research literature.

A common perception is that student leave STEM majors because of poor academic ability or financial difficulty. However, research suggests that decisions to leave STEM majors arise from a multitude of factors. "Switching" from a STEM major to a non-STEM major is not an event, but a process based on a set of issues—curricular, instructional, and cultural—or from students' concerns about their career prospects (Seymour, 1992; Seymour and Hewitt, 1997; Seymour, 2001).

Seymour identified several reasons that prompt students to leave STEM majors:

- Poor teaching by faculty
- Inadequate academic advising and career counseling
- Conceptual difficulties with one or more subjects
- Unexpectedly long times to complete major requirements (i.e., more than four years)
- Language barriers associated with international instructors
- Financial problems
- Course load and pace

- Inadequate high school preparation.

It seemed natural to the committee to question whether and to what extent these factors cited in the research influence the decisions of ASU students to leave the STEM pathway. We therefore constructed a survey that included clusters of items that address students' feelings on the issues identified in the literature. As detailed below, we also examined the nature of instruction in ASU STEM classrooms (save for mathematics), the nature of assessments, and how well students' high schools had prepared them for college-level coursework in mathematics and science.

4.2 Survey of ASU's Freshman STEM-Leavers

The committee identified 862 students who, according to Data Warehouse, switched from a STEM major to a non-STEM major during their freshman year.[8] We contacted these students, explaining our reason for contacting them, and requested that they complete an online survey.[9] The survey asked about their reasons for leaving their STEM major and asked them to compare their new and old majors in a number of areas. Three hundred forty-five students responded, for a response rate of 40%.

The survey revealed a number of important differences in students' feelings about their new and old majors.

- Students were much more satisfied with advising and career counseling in their non-STEM major than in their STEM major and felt that their new major gave them greater career options (Table 32)

- Students felt that they experienced more conceptual difficulty, more problems related to class size, and poor recitation support in STEM majors compared to their new majors. Students also experienced lower morale due to the competitive culture and felt that they lacked peer support in STEM majors compared to the new majors (Table 33)

- Students felt that STEM faculty were less approachable than faculty in the new major, and they were less satisfied with the quality of instruction in STEM courses.[10] Students had greater language difficulties with international faculty or TAs and students felt that they lacked research opportunities with faculty while enrolled in STEM (Table 34)

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[8] We queried Data Warehouse for students whose freshman year occurred during the 2001–2002, 2002–2003, 2003–2004, or 2004–2005 academic years.
[9] Students were entered into a raffle for two iPods upon completing the survey.
[10] Students' major contact with instructors is through instruction, so we assume that it is a faculty's instruction that they rated and not the instructor per se.

- Among STEM leavers, engineering students (but not other STEM students) expressed difficulty balancing work and course load compared to the new major. Their "outside job made it more difficult to complete their degree" and they expected the degree to take more than four years.

- Interestingly, differences between the STEM major and new major for "curriculum load" and curriculum pace" were not significant.

- Among all STEM majors (including engineering), students did not claim financial problems as a reason for leaving.

- Former engineering students felt that they lacked adequate high school preparation for their majors. In contrast, non-engineering STEM students felt better prepared for their STEM major than for their new major (Table 36). This was true not only for non-engineering areas collectively; it was true of individual areas.

- Students received better grades in their new majors compared to their STEM majors (Table 37). Engineering majors experienced a greater improvement in comparison to their freshman GPA's than did non-engineering students, primarily because a larger percent of engineering had less than a 2.0 grade point average before they switched than did non-engineering majors.

In summary, STEM students were more satisfied with the student and classroom cultures in their new majors. They found faculty in their new major easier to approach and, from students' perspectives, to provide higher-quality instruction. They found better advising and counseling in their new major. And their grades improved markedly in their new majors.[11]

4.3 Instruction in STEM courses

The persistence results given earlier, and the survey of STEM leavers, suggested to the committee that the nature of instruction in STEM courses might be a factor in the low persistence rates among STEM majors. In investigating this possibility, we first needed to adopt an instrument that would give us a standardized metric against which to characterize the nature of instruction that students experienced. We used the Reformed Teaching Observation Protocol (RTOP, Sawada, Piburn, Falconer et al., 2000; Sawada, Piburn, Turley et al., 2000), developed by the Arizona Collaborative for Excellence in the Preparation of Teachers, to do this.

In brief, the RTOP measures the degree to which instruction engages students in ways that the best available research suggests enable people to learn meaningfully (Bransford, Brown & Cocking, 2000). That research strongly suggests that people learn most effectively in student-centered rather than instructor-centered

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[11] This is not to say, however, that their grades would not have improved in their STEM major.

classrooms. In a student-centered learning environment, the instructor focuses on uncovering what students are thinking and providing them with experiences that push their thinking in productive directions. The goal is to help students develop as independent, logically adept thinkers and problem-solvers. By contrast, in an instructor-centered classroom, the teacher is focused on “performing” an instructional narrative, with only cursory attention given to how students are understanding the performance. The assumption in instructor-centered pedagogy is that teachers talk and students learn.

Research further favors instruction that is highly interactive and gives control to students at appropriate times.

The RTOP items are designed to favor student-centered actions by the instructor and student-centered lesson design. Lessons that are very instructor-centered, with little instructor-student interaction, get lower scores.[12]

It is worth noting that the National Science Foundation, the State of Arizona, and several other states have adopted the RTOP as their standard measure of instruction. It is also worth noting that while RTOP attends to the type of content that a lesson entails, it does not evaluate the quality of content in instruction. Excellent content can be taught poorly, and poor content can be taught excellently. RTOP is largely neutral in this regard.

The RTOP has three major parts: Lesson Design and Implementation, Content, and Classroom Culture (see Appendix III, p. 66).

The committee engaged the services of Dr. Michael Piburn, one of the original RTOP developers, to train a team of graduate students in using the RTOP. Training followed a standardized method that consisted of a series of workshops over a three-week period in which observers studied the instrument, practiced applying it in the context of videotaped lessons, and then practiced applying it in the context of actual lessons taught at a local community college.

Observations were arranged for courses in introductory biology, chemistry, and physics.

The Department of Mathematics and Statistics, with the support of Dean Sid Bacon, declined to allow observations of calculus instruction. Also, we attempted to include several introductory engineering courses but could not because of scheduling conflicts. In all, 12 instructors participated.

One pair of observers attended each course three times over the semester (both observers attending the same lessons). Each observer scored each lesson

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[12] There is some controversy about the extent to which content scores are influenced by the content expertise of the RTOP observer; the committee addressed this issue by using graduate students who had backgrounds in the subjects they observed.

independently. Ms. Nora Ramirez, the committee's RTOP coordinator, gave instructors an identification number, and those numbers were placed on observation records. The committee cannot tell by looking at an observation record which instructor was observed. Members could tell only that the lesson observed was, for example, a chemistry lesson, and that the instructor was Number 101.

Correlations among item scores by observer pairs per lesson ranged from 0.49 to 1.00 (Figure 1). Two observations produced item correlations less than 0.55. All other correlations were 0.70 or higher. It is interesting to note that the two lowest correlations are from observations in which the two observers' total lesson scores were nearly identical. A plot of the average observation score per lesson in relation to the difference between the two total observation scores (Figure 2) shows that most total lesson scores per observed lesson were relatively close. We therefore used the average of the two observers' lesson scores per lesson as our unit of analysis. There were 36 lessons observed in all: six biology, 12 chemistry, and 18 physics. All lessons were in large lecture settings (more than 120 students).

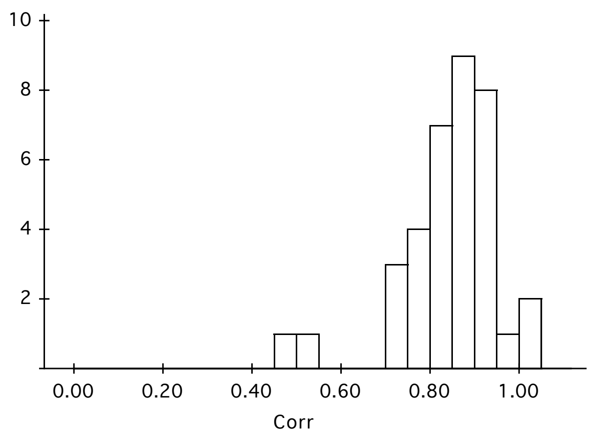

Figure 1. Correlations among observer pairs' item scores per lesson observed (n=36).

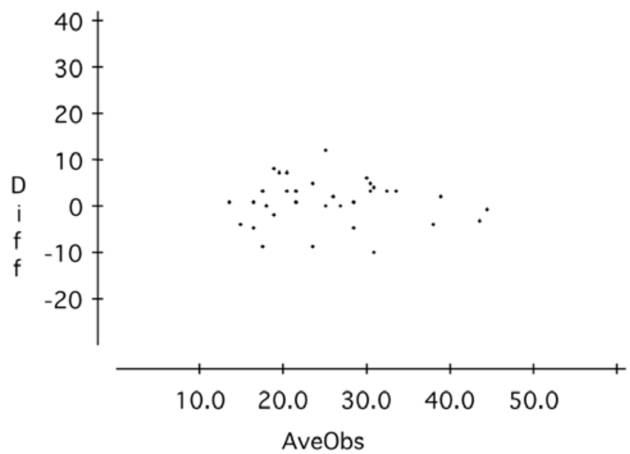

Figure 2. Differences between total observation lesson scores in relation to average total lesson observation score. (n=36).

Total lesson scores ranged from 13.5 to 44.5 with a mean of 25.1 and a median of 23.5. Distributions varied by subject. Figure 3 shows that biology lessons tended to be more student-oriented than chemistry or physics lessons, although all lessons were heavily instructor-centered.

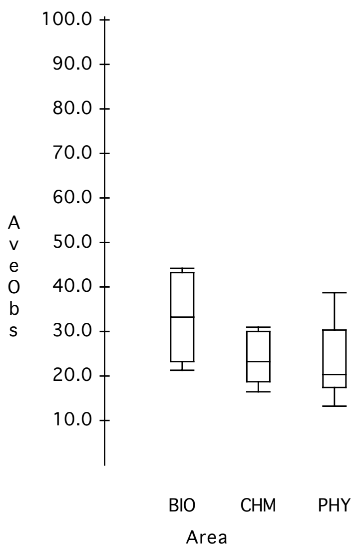

Figure 3. Distribution of total RTOP scores per area.

4.4 Assessments

Students' experiences in introductory STEM courses are influenced by many factors. One of them is the kind of knowledge they are expected to learn. Students often are put off by courses they see as full of facts and procedures to be memorized, and they often are energized by courses that challenge and foster their creativity and insight.

The committee examined tests from calculus, biology, chemistry, physics, and engineering in its attempt to understand the kind of knowledge students were being expected to learn. We clearly could not examine every test given over the past five years, so we obtained samples from past and current courses. We have no way of judging whether the sample is representative of the totality of assessments in ASU's STEM courses, but the tests seemed reasonably representative to committee members with backgrounds in the areas from which the tests were taken.

The committee also needed a framework by which to judge the nature of knowledge assessed by test questions. For this we used the Taxonomy of Educational Objectives as developed by a group of psychologists headed by Benjamin Bloom (Bloom, 1956).

The Bloom taxonomy addresses objectives at six levels of cognitive processes:

> The taxonomy begins by defining **knowledge** as the remembering of previously learned material. Knowledge, according to Bloom, represents the lowest level of learning outcomes in the cognitive domain. Knowledge is followed by **comprehension**, the ability to grasp the meaning of material and goes just beyond the knowledge level. Comprehension is

> the lowest level of understanding. **Application** … refers to the ability to use learned material in new and concrete principles and theories. Application requires a higher level of understanding than comprehension.
>
> In **analysis** … the learning outcomes require an understanding of both the content and the structural form of material. Next is **synthesis**, which refers to the ability to put parts together to form a new whole. Learning outcomes at this level stress creative behaviors with a major emphasis on the formulation of new patterns or structures. … **Evaluation** is concerned with the ability to judge the value of material for a given purpose. The judgments are to be based on definite criteria. Learning outcomes in this area are the highest in the cognitive hierarchy because they incorporate or contain elements of knowledge, comprehension, application, analysis, and synthesis. In addition, they contain conscious value judgments based on clearly defined criteria. (Bellis, 2007)

In applying the Bloom taxonomy to course examinations, the committee, as a whole, discussed individual questions until it reached consensus on their places in the taxonomy. When the committee members felt that they had a common understanding of how to apply the taxonomy, each took responsibility for categorizing the items on exams in his or her area. Discussions of individual items that seemed difficult to classify continued over several meetings. Appendix IV provides examples of test items and their classifications.

Table 38 presents results of our analyses of introductory STEM course examinations.[13] Several aspects of these results stand out:

- First, there are clear differences among the cognitive processes assessed by various subjects. Biology tests and mathematics tests tend to be heavier than other subjects on knowledge and comprehension items

- Second, there are clear differences among instructors within subjects as to the cognitive processes they assess. CHM tests 6 and 10 were given by the same instructor; MAT tests 7, 12, 13, and 17 were by two instructors. The other 13 MAT tests were given by five instructors

- Third, taken as a whole, it is rare for a student in any of these classes to be asked to reason at the level of synthesis and evaluation, and common—especially in mathematics—for students to be able to cope in a class by memorizing material on which he or she is tested

[13] Clearly, this is a convenience sample and cannot be assumed to be representative, except perhaps for calculus exams.

4.5 Students' Mathematical and Scientific Preparation

Students' high school preparation in mathematics and in science clearly is an issue with regard to college level work at ASU. A plethora of indicators point to problems in this area. Arizona's pass rates for advanced placement tests in mathematics are approximately half the national pass rate (the Arizona rate is 2.8% of graduating seniors, versus 5.2% nationally) and pass rates in science are lower yet (the Arizona rate is 2.0% of graduating seniors, versus 4.0% nationally).

Students' SAT-Q scores are an indicator, albeit imperfect, of students' preparation. Average entering SAT-Q scores in each area are given in tables 39 and 40. An SAT-Q score of 600 is at the national 75th percentile. An SAT-Q score of 670 is at the 90th percentile.

ASU persisters and droppers differed in average SAT-Q score by approximately 40 points (85th percentile versus 75th percentile), but SAT-Q is not a good predictor of who will persist and who will not.

An ANOVA of ASU drop rates relative to SAT-Q percentile rank gives an overall p-value less than 0.001, but the only Scheffé comparisons having a p-value less than 0.20 are between percentile ranks above 90% and most lower percentile ranks (Table 41).

The committee did not have access to students' high school transcripts, but it could discern which students entered ASU with AP or transfer credit in calculus. An ANOVA of ASU drop rates among students whose current majors require two or three semesters of calculus (and who had adequate time to finish their calculus requirements) shows that students who entered with credit for MAT 270 or MAT 271 were significantly less likely to drop from ASU than were students who started with MAT 270 ($F = 541.6$, $p < 0.0001$; Table 42). The former had an ASU drop rate of 19%, while the latter had an ASU drop rate of 56% (Table 43).

Another indicator of student preparation comes from the Mathematics Department's pilot in spring 2007 of the University of California's math placement test. Thirty-three percent (33%) of non-engineering Calculus 1 students passed with a score of 60% or higher; 70% of engineering Calculus 1 students passed. The department will use this placement exam to put students in courses that match the students' preparation. Students who do not pass the placement exam will be enrolled in MAT 170, Precalculus Mathematics. This is a traditional course for preparing students to take calculus.

Examination of MAT 170 as Preparation for Calculus

Because the Mathematics Department will rely heavily on MAT 170 to help mathematically under-prepared students who want to take calculus succeed in doing so, the committee decided to examine the effectiveness of MAT 170 at preparing students for calculus.[14]

We found that students who take calculus after taking MAT 170 do quite well (Table 44). Over 80% of students who go on to complete a calculus course receive a C or higher in their first calculus course.

Unfortunately, relatively few students who should go on to calculus actually do. Half of declared engineering majors did not take calculus after MAT 170 (Table 45). Almost two-thirds of declared life science majors, math majors, and physical science majors who took precalculus chose not to take calculus. This suggests strongly that these students did not persist in their desired major, as to have persisted would have required that they take calculus.[15]

To see if, in any area, students chose not to continue because of poor grades, the committee restricted the data in Table 45 to students receiving at least a C in precalculus.

We see in Table 46 that 38% of engineering students who received a C or better in precalculus chose not to take calculus. Over half of students who had declared a major in life sciences, mathematics, or physical sciences and received at least a C in precalculus chose not to take calculus. Moreover, of the students who had received at least a C in MAT 170 and who had not declared a major—a pool of students from which we should attract STEM students—60% chose not to take a calculus course after completing precalculus.

Finally, the committee considered the possibility that the best students in precalculus continue to calculus at differentially higher rates. Table 47 shows that this is not the case.

Forty-three percent of students who receive an A in precalculus and who had declared a STEM major that requires calculus chose not to take calculus. In other words, even the very best students in precalculus who thought they wanted to enter a STEM major are leaving STEM.

The data in tables 44-47, which show that even successful precalculus students who have declared a major that requires calculus decide not to take calculus, tells the committee that there is a problem with precalculus aside from students' lack

[14] Calculus courses are MAT 210 for business, MAT 251 for life sciences, MAT 270 for life sciences, mathematics, and physical sciences, and, as of fall 2006, MAT 265 for engineering.

[15] Our lookup formula detected whether students signed up for any of MAT 210, MAT 251, MAT 270, MAT 271, or MAT 272. So, if a MAT 170 student who had a calculus requirement took calculus at a community college, he or she fulfilled *all* calculus requirements at a community college.

of preparation. It suggests that students are being driven by something they experience in precalculus to rethink their goals even in light of success.

Given that the precalculus experience seems to deter potential STEM candidates, the committee suspects that placing students into precalculus, in its existing form, will neither recruit more students to, nor retain more students in, STEM majors.

5. Committee's Discussion

Persistence rates at ASU among STEM students, both within course sequences and within ASU, are unacceptably low.

The students we are losing are ones who *chose* STEM majors as their initial majors. These students thought they wanted to be engineers, mathematicians, or scientists. Students making these choices are uncommon among high school graduates who enter ASU. Their choice means that they enjoyed, at some level, mathematics or science, and entertained the possibility that they would pursue a STEM career. Arizona cannot afford to lose these students.

The results of our analyses are in line with a series of landmark studies on the nationwide problem of retaining STEM majors. Seymour (2006) summarized this research in testimony to Congress. She noted that, contrary to what is commonly assumed, students do not leave STEM majors primarily for financial or academic reasons. Instead, they leave STEM majors because they think the instruction is poor and the atmosphere is uncaring. The committee's survey of STEM-leavers confirmed that ASU students leave for the same reasons.

Poor instruction, however, is in the eye of the beholder. If students do not understand what is taught, or see little value in it, then they are likely to think instruction is poor. But there are two perspectives from which we can interpret students' claims of poor instruction. If we take *instruction as given* and ask why students do not understand it and why they see little value in it, then our answer will point to inadequacies in students' knowledge and value systems. If we take *students as given* and ask why they do not understand instruction and ask why they see little value in it, then our answer will point to inadequacies in instruction.

The committee recognizes that ASU does not attract high-achieving students in the same proportions as do many of its peer universities.[16] However, it has the students it gets. As Arizona's largest institution for undergraduate education, surely the overriding responsibility of ASU as a socially embedded university is to give the students we get the instruction they need. The committee unanimously believes that it is incumbent upon ASU to understand and address the problems that underlie its anemic retention rates for STEM majors.

It seems that Seymour's point (made many times by many different people) is apt: U.S. university faculties are not rewarded for attention to excellent learning and thus ignore work by committees such as ours without consequence. Untenured professors are punished for giving too much attention to teaching. Tenured

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[16] A 2007 CLAS comparison of ASU with aspirational and operational peers noted that 26% of ASU's incoming freshmen were in the top 10% of their graduating class, whereas 66% of the University of Washington's incoming freshmen were in the top 10% of their graduating class.

professors are rewarded for advances in research, not excellence in learning. The highest raises are given to the most productive researchers.

Interestingly, however, ASU does not fit this mold entirely, at least in mathematics. It has a first-year mathematics faculty that is well paid by national standards, and introductory mathematics is their sole mission.[17] Why, then, do we have such high attrition rates in mathematics? In answering this we again point to the two perspectives from which we can answer: Take instruction as given and look for inadequacies in students, or take students as given and look for inadequacies in instruction and programs.

We believe that the only practical solution is to focus on working with the students we have and not on the students we wish we had. We must ask ourselves, therefore, whether the instruction we provide in entry-level STEM courses is the instruction ASU students need.

5.1 Teaching the Students We Have

The revolution in mindset necessary to take students as given and provide the instruction they need is so pivotal, and so often counter to university culture, that the committee believes it must be emphasized at the highest levels of university leadership.

The committee agrees with the maxim, "Teach the students you have, not the students you wish you had" (attributed to Clarence Stephens, of SUNY Potsdam, by Spencer, 1995, p. 862). Spencer said this in the context of describing the approach taken at Potsdam, where 25% of their students graduated with a B.A. in mathematics, notwithstanding that the average entering combined SAT was 980. He also addressed the question of whether Potsdam's success in attracting and retaining mathematics majors was due to lowered expectations of what students could achieve.

> It is natural to ask, "Have they simply lowered standards to keep more students?" The answer is yes and no. If by "lowering standards" we mean dealing with less material in order to have the students actually be able to do something beyond merely repeating what they've been told, the answer is usually yes. If by "lowering standards" we mean accepting students at the level we find them and having them grow from that point, the answer is almost always yes. If by "lowering standards" we mean working with students for whom studying mathematics is a challenge and waiting for those students to

[17] The number of calculus sections in calendar years 2003-2005 increased from 102 to 109 while the number of sections taught by tenure track faculty decreased from 27 to 13. In Spring 2007, only one MAT 270-272 instructor was a member of the tenure track faculty.

> develop rather than dealing only with the naturally precocious students, the answer is definitely yes. If, however, lowering standards means replacing proof with example, replacing understanding with rote memorization, replacing analysis with algorithm, the answer is no. If by "lowering standards" we mean sending students into the world ill prepared to compete, the answer is no. (Spencer, 1995, p. 860)

Two related points from Spencer's analysis of the Potsdam experience are worth noting. First, he notes that the oft-expressed need "to cover the material" cannot be an instructor's primary obligation. "I need to cover the material" cannot be an excuse for choosing not to engage in high quality instruction.

Second, Spencer notes that Potsdam resisted the temptation of large lecture classes.

> We have kept the enrollment in classes moderate: forty in the lower-division courses, twenty-five to thirty in the upper division, and fifteen in the Problem Seminar. We have resisted going to large lecture sections. We believe that the single most important thing that keeps students encouraged and persisting in mathematics courses is not a career objective nor a technological experience, but careful teaching, especially at the freshman and sophomore level. (Spencer, 1995, p. 861)

We note that while refraining from large lecture classes is a feature of the Potsdam model, it is not sufficient for the kind of excellent instructional programs that Potsdam typifies. Physics, chemistry, and biology use large-lecture formats while mathematics does not. It is difficult for students to develop a sense of community in large classes, but small classes do not guarantee it.

Potsdam is not a peer university of ASU, yet the committee views its efforts as one example of numerous best practices worth our continued study (the mathematics program at the University of Arizona, described in Appendix VI, is another exemplar).

The committee is concerned, however, that many first-year mathematics faculty at ASU do not share the Potsdam philosophy. In a recent public discussion of "most important issues" regarding requirements that entering mathematics students should meet, comments that ASU should raise its entry standards and that students should not be allowed to take mathematics until they are adequately prepared dominated the discussion. The committee believes these comments reflect a strong desire on the part of FYM faculty to restrict the students they are required to teach, not teach the students they have.

5.2 Student Preparation

Proper placement of students in courses whose content and instruction match students' capabilities is undoubtedly a wise strategy. It is the first tenet of the University of Arizona's renewal of its undergraduate mathematics program (see Appendix VI). But it is important to consider whether the program into which students are placed is designed to actually work with where students are and is designed to help them achieve what they hope to achieve.

The Mathematics Department's planned strategy of having students pass the UC placement exam before allowing them to enroll in MAT 270 (or the new version for engineers, MAT 265) will undoubtedly improve success rates in calculus. But lack of success in calculus is not the primary reason students leave. Even when students are separated into engineering and non-engineering tracks, if nothing else changes then the instruction they receive will be of the same genre. The survey of STEM leavers supports Seymour's findings that the primary reason students leave is that they perceive instruction to be memory-oriented and that they find the culture to be one with which they would rather not identify. We once again urge departments to "Teach the students you have, not the ones you wish you had."

6. Committee Recommendations

In the committee's view, there is incontestable evidence that ASU students leave STEM majors because of perceived poor instruction and an alienating culture. ASU cannot keep more students in these majors just by offering different courses or reducing class sizes.

In its study of best practices, the committee found strong examples in the University of Buffalo's strategy for addressing low engineering persistence rates, SUNY Potsdam's approach to recruiting and retaining undergraduate mathematics majors, and the University of Arizona's strategy to improve its undergraduate mathematics programs (see Appendix VI).

There are particularly stubborn issues in ASU's mathematics programs. The committee finds it highly problematic that the tenured mathematics faculty has so little stake in lower division mathematics programs and instruction. While this is surely not the sole factor in the problem of high calculus attrition rates, we believe that reform of calculus instruction will be difficult to achieve without significant buy-in from the department's tenured faculty.

The committee sees the overall problem of low persistence in STEM at ASU as being one of culture and environment. This overall problem, in turn, entails issues of curriculum, instruction, and institutional support.

The most difficult aspect of improving the university's outcomes in freshman STEM programs may lie in first **acknowledging the size of the challenge we face.** The committee recommends reforms that span the spectrum of the university's operations—from faculty's conception of what "good teaching" means to the university's systems for evaluating faculty performance to ASU's engagement with K-12 practice and the Arizona Department of Education.

Obstacles loom at each stop along this spectrum of reform. University leaders must be prepared to meet resistance and to commit significant resources to this endeavor.

For example, the committee recommends that teaching in freshman STEM programs follow a student-centered methodology. But more than a decade of reform efforts funded by the National Science Foundation (in postsecondary engineering education, physics, and mathematics and science at the K-12 level, for instance) have shown that fundamentally changing the way one teaches can easily take three to five years and cannot happen in isolation of changes in peer communities or in isolation of changes in institutional values.

Conservatively speaking, research has shown that genuinely reforming to student-centered teaching requires that instructors:

- Rethink the material they teach, deconstructing complex systems of ideas into basic concepts and uncovering the connections among them
- Build new lessons that reflect this deconstructed understanding of the material
- Master new and still-emerging knowledge about human learning and cognition
- Learn a repertoire of techniques for uncovering and understanding student thinking
- Move the focus of classroom attention from a tidy lesson narrative playing out in the teacher's mind to the decidedly untidy tableau of struggle-for-understanding playing out in the student's mind
- Have the opportunity to observe and receive intensive coaching in on-the-fly classroom techniques that push student thinking
- Learn to develop assessments that probe the logic and confidence of student thinking, rather than simply checking for right answers
- Accept that each teacher's teaching must be open to fellow teachers for constructive, collegial observation and critique
- Discard the oft-proffered claim that the need to "cover the material" makes it impossible to adopt more effective teaching strategies
- Form and engage in an ongoing community with fellow instructors to discuss content, building and refining lessons, examining and discussing student work, and observing and helping to improve one another's pedagogy

The National Science Foundation has for decades funded research on the reform of mathematics and science teaching. One thing this research has established is that **an instructor must first acknowledge that his or her teaching is problematic before any substantive changes in instruction happen.**

Many instructors do not accept that their teaching might be problematic in ways that impede student learning. In their view, students are the problem. We suspect that a close examination of freshman courses in STEM departments would reveal this to be a common attitude among instructors.

Three other points bear emphasizing before we list the committee's recommendations.

First, the committee feels that departments in the STEM disciplines must leverage research on learning and teaching in science and mathematics education. One clear example of this is the way that the VanTH (Vanderbilt, Texas, Harvard/MIT Engineering Research Center) for bioengineering and educational technologies has leveraged the research captured in *How People Learn* (Bransford, Brown, & Cocking, 2000) to transform instruction in biomedical and bioengineering education. Science and mathematics education research, applied thoughtfully, can provide guidance for reforms that respect both students' identities and the disciplinary knowledge that students must develop.

Second, the committee does not mean to underestimate the problem that students arrive at ASU ill-prepared for college-level work in the STEM disciplines. Instead, we believe that ASU and the other state universities have been too timid in their engagements with K-12 education. We recommend that the universities actively assist the state in setting learning standards, developing assessments, and aligning curriculum that will prepare students to succeed in college.

Third, the committee feels strongly that a university-wide commitment to the improvement of STEM instruction cannot happen without a simultaneous commitment to collegiate STEM education research. Many of the STEM departments have a history of supporting STEM education, and several others are attempting to do so. But such support waxes and wanes and has never reached a critical mass. We feel that the kind of reform in STEM education that ASU faces cannot be accomplished without a concomitant university-wide commitment to STEM education research.

I. Recommendations Relating to Process and Structure

Recommendation 1: The provost distribute this report to departments with the request that each one (1) engage in a process of self study to understand the reasons for low retention and persistence rates, (2) prepare a response and an action plan addressing how they will improve retention and persistence rates, and (3) propose and justifyrealistic goals for persistence and retention as measured in this report.

Recommendation 2: To support the work of the departments, establish an interdepartmental coordinating committee and a provost-level undergraduate STEM advisory committee.

II. Recommendations Relating to Incentives

Recommendation 3: Establish a system that rewards departments for high persistence rates (say, at least 80% retention from one course to another) and high retention rates (say, at least 80% of its majors actively pursuing their degrees).

Recommendation 4: Establish a system that rewards instructors of entry-level courses for adopting and modeling student-centered methods of instruction as measured by RTOP. In addition, establish a system for rewarding instructors whose students exhibit persistence rates of 80% from one course to another. Finally, create something like a Barrett Honors College that will function as a virtual college constituted by tenure-track faculty who have declared a scholarship of teaching as their primary emphasis.

III. Recommendations Relating to Evaluation of Instruction

Recommendation 5: Establish an evaluation-of-instruction system that goes beyond end-of-semester student questionnaires. The committee feels that RTOP would be an especially appropriate evaluation instrument and recommends that it be used in addition to student evaluations.

Recommendation 6: Each department draw on the expertise of its mathematics education or science education faculty in improving introductory STEM instruction and curricula.

IV. Recommendations Relating to Instruction

Recommendation 7: Departments should adopt and use learner-centered pedagogy as promoted by ABOR (http://www.abor.asu.edu/4_special_programs/lce/general_lce.html), such as small group learning, cooperative and active learning, interdisciplinary teaming, etc.

Recommendation 8: Provide workshops for instructors, teaching assistants, and faculty that address issues of scientific teaching[18] and best practice in science pedagogy[19], and expand opportunities for undergraduates to participate in research mentored by a faculty member.

V. Recommendations Relating to Special Concerns in Precalculus/Calculus

Recommendation 9: While each department studied by this committee has retention problems that will likely require special attention to the nature of its field and subfields, the committee sees calculus and precalculus as needing special attention. The committee recommends two courses of action: (1) Provost Capaldi and Dean Wheeler create an oversight committee composed of representatives from departments whose students take calculus to advise the Mathematics Department on their students' needs; (2) the mathematics

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[18] See, for example, http://www.sciencemag.org/cgi/content/full/304/5670/521.
[19] See UCSB International TA Handbook http://www.oic.id.ucsb.edu/TA/ and Understanding International Instructors (for undergraduates) http://www.indiana.edu/~comu/instruct.html;

department draw on the expertise of its mathematics education group and the expertise of award-winning members of its mathematics faculty to improve the quality and content of calculus and precalculus instruction.

VI. Recommendations Relating to Student Advising

Recommendation 10: Convene all ASU advisors who are engaged in counseling students in the STEM disciplines. Direct them to prepare a report for Provost Capaldi and college deans that assesses the current condition of STEM advisement and recommends improvements. Incorporate in this report recommendations for leveraging outreach programs such as the SUMS Institute, MESA, Sally Ride programs, etc.

VII. Recommendations Relating to K-12 Student Preparation

Recommendation 11: Form a university committee that will recommend to the provost and the president strategies by which ASU can exert leadership in the mathematical and scientific preparation of Arizona school students.

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7. Tables

Table 1. Persistence rates per area from MAT 270 to MAT 271 among students whose majors at the time of enrolling in MAT 270 required at least 2 semesters calculus. Cell entries are counts and percents of column total. 6793 students received a grade in MAT 270 during this time period; 2222 of those students were not required to take MAT 271.

MAT 270→271, 271 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	1202 43.0	0 •	136 54.4	262 51.1	505 49.9	2105 46.0
Persisted	1595 57.0	0 •	114 45.6	251 48.9	507 50.1	2467 54.0
total	2797 100	0 100	250 100	513 100	1012 100	4572 100

Table 2. Grades among students in MAT 270 over the period Fall. 2001 to Spring, 2006.

MAT 270 Grades	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Tech*	*total*
A	25.4	32.8	26.9	30.3	28.0	20.8	26.5
B	25.4	24.8	20.7	23.8	21.0	25.6	24.5
C	24.8	21.6	24.1	19.5	22.8	23.2	22.8
D	4.79	1.60	2.76	4.52	4.40	5.84	4.70
E	10.3	8.80	9.66	7.49	10.6	12.3	9.79
W	8.40	10.4	13.8	13.6	11.1	10.6	10.6
X	0.939	0	2.07	0.777	2.07	1.59	1.09

Table 3. Persistence rates per area from MAT 270 to MAT 271 among students who received a C or higher in MAT 270 and whose majors at the time of enrolling in MAT 270 required at least 2 semesters calculus. Cell entries are counts and percents of column total.

MAT 270→271, 271 Required, ≥ C in 270	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	449 30.4	46 44.2	108 39.0	176 33.7	779 32.7
Persisted	1029 69.6	58 55.8	169 61.0	347 66.3	1603 67.3
total	1478 100	104 100	277 100	523 100	2382 100

Table 4. Grades of students taking MAT 270, getting C or better, whose majors require MAT 271, and who did not persist in MAT 271.

A	139	17.8%
B	252	32.3%
C	388	49.8%

Table 5. Persistence rates per area from MAT 271 to MAT 272 among students whose majors at the time of enrolling in MAT 271 required 3 semesters calculus. Cell entries are counts and percents of column total.

MAT 271→272, 272 Required	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	819 44.1	54 38.8	65 47.8	261 42.1	1199 43.6
Persisted	1038 55.9	85 61.2	71 52.2	359 57.9	1553 56.4
total	1857 100	139 100	136 100	620 100	2752 100

Table 6. Persistence rates per area from MAT 271 to MAT 272 among students whose majors at the time of enrolling in MAT 271 required 3 semesters calculus and who received at least a C in MAT 271.

MAT 271→272, 272 Required, ≥ C in 271	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	482 32.2	31 27.2	28 29.2	127 26.8	668 30.7
Persisted	1013 67.8	83 72.8	68 70.8	346 73.2	1510 69.3
total	1495 100	114 100	96 100	473 100	2178 100

Table 7. Persistence rates per area from MAT 271 to MAT 272 among students who began calculus with MAT 271 and whose majors required 3 semesters of calculus.

MAT 271→272, 272 Required, Began w/271	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	193 33.4	15 25.4	14 43.8	55 33.1	277 33.2
Persisted	385 66.6	44 74.6	18 56.2	111 66.9	558 66.8
total	578 100	59 100	32 100	166 100	835 100

Table 8. Persistence rates per area from MAT 271 to MAT 272 among students who began calculus with MAT 271, whose majors required 3 semesters of calculus, and who received at least a C in MAT 271.

MAT 271→272, 272 Required, Began w/271, ≥ C in 271	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	129 25.4	11 20	7 29.2	29 21.0	176 24.3
Persisted	378 74.6	44 80	17 70.8	109 79.0	548 75.7
total	507 100	55 100	24 100	138 100	724 100

Table 8a. Repeated enrollments in calculus classes.

	# Times Taken		
No. Students	*MAT 270*	*MAT 271*	*MAT 272*
1	3	2	4
1	2	2	3
18	3	3	
21	2	2	2
102	3	2	
328	2	2	
417	3		
2557	2		

Table 8b. Persistence at ASU of students who stay in or switch to a STEM major that requires 2 or more semesters of calculus.

Persistence at ASU (current major)	*Engr*	*Math*	*Phys Sci*	*Tech*	*total*
Comp Req (Same maj)	909 43.8	81 28.2	142 30.7	271 37.8	1403 39.6
Comp Req (Sw maj)	336 16.2	121 42.2	131 28.3	80 11.2	668 18.9
Drop ASU (Same maj)	708 34.1	47 16.4	129 27.9	307 42.8	1191 33.6
Drop ASU (Sw maj)	122 5.88	38 13.2	61 13.2	59 8.23	280 7.91
total	2075 100	287 100	463 100	717 100	3542 100

Table 8c. Number of calculus courses completed before dropping from ASU (major requires 1, 2, or 3 courses).

Number of courses	*0*	*1*	*2*	*3*	*total*
Drop ASU (Same maj)	449	487	423	0	1359
	33.0	35.8	31.1	0	100
Drop ASU (Sw maj)	86	136	130	0	352
	24.4	38.6	36.9	0	100
total	535	623	553	0	1711
	31.3	36.4	32.3	0	100

Table 8d. Number of calculus courses completed before dropping from ASU (major requires 1 or 2 courses)

Number of courses	*0*	*1*	*2*	*3*	*total*
Drop ASU (Same maj)	74	36	0	0	110
	67.3	32.7	•	•	100
Drop ASU (Sw maj)	59	33	0	0	92
	64.1	35.9	•	•	100
total	133	69	0	0	202
	65.8	34.2	100	100	100

Table 8e. Distribution of MAT 270 grades per area among students who dropped from ASU.

	Engr	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
A	177	0	12	34	42	265
	21.6	0	16.9	17.5	12.1	17.9
B	142	0	13	27	76	258
	17.3	0	18.3	13.9	22.0	17.4
C	185	0	16	43	70	314
	22.5	0	22.5	22.2	20.2	21.2
D	39	0	3	13	23	78
	4.75	0	4.23	6.70	6.65	5.27
E	167	22	12	33	71	305
	20.3	44.9	16.9	17.0	20.5	20.6
W	97	26	11	36	54	224
	11.8	53.1	15.5	18.6	15.6	15.1
X	14	1	4	8	10	37
	1.71	2.04	5.63	4.12	2.89	2.50
total	821	49	71	194	346	1481
	100	100	100	100	100	100

Table 8f. Distribution of MAT 271 grades per area among students who dropped from ASU.

	Engr	*Math*	*Phys Sci*	*Tech*	*total*
A	104 20.0	5 8.93	5 5.10	24 11.8	138 15.7
B	111 21.3	11 19.6	14 14.3	30 14.8	166 18.9
C	100 19.2	13 23.2	13 13.3	36 17.7	162 18.4
D	36 6.92	8 14.3	2 2.04	18 8.87	64 7.28
E	93 17.9	10 17.9	26 26.5	52 25.6	182 20.7
W	73 14.0	9 16.1	36 36.7	42 20.7	161 18.3
X	3 0.577	0 0	2 2.04	1 0.493	6 0.683
total	520 100	56 100	98 100	203 100	879 100

Table 9. Persistence rates per area from BIO 187 to BIO 188 among students completing BIO 187.

BIO 187→188	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Pre Med*	*Tech*	*Undclrd*	*total*
Dropped	40 30.8	489 43.9	8 66.7	587 63.3	93 41.3	237 47.3	31 81.6	209 51.6	1694 50.5
Stayed	90 69.2	625 56.1	4 33.3	341 36.7	132 58.7	264 52.7	7 18.4	196 48.4	1659 49.5
total	130 100	1114 100	12 100	928 100	225 100	501 100	38 100	405 100	3353 100

Table 10. Persistence rates per area from BIO 187 to BIO 188 among students whose majors require BIO 188.

BIO 187→188 188 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	22 22.2	462 43.6	0 •	63 39.1	237 47.3	0 •	784 43.1
Persisted	77 77.8	597 56.4	0 •	98 60.9	264 52.7	0 •	1036 56.9
total	99 100	1059 100	0 100	161 100	501 100	0 100	1820 100

Table 11. Persistence rates per area among students in BIO 187 whose majors require BIO 188 and who received at least a C in BIO 187.

BIO 187→188, 188 Required, ≥C in 187	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	14 16.7	271 32.2	0 •	43 33.3	105 30.8	0 •	433 31.0
Persisted	70 83.3	570 67.8	0 •	86 66.7	236 69.2	0 •	962 69.0
total	0 100	841 100	0 100	129 100	341 100	0 100	1395 100

Table 11a. Persistence per area at ASU of students who stay in or switch to a STEM major that requires BIO 187 and BIO 188

Persistence at ASU (current major)	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*total*
Drop ASU & Same maj	13 18.8	284 26.0	0 0	40 23.8	101 76.5	438 29.9
Drop ASU & Sw Maj	3 4.35	107 9.79	0 0	17 10.1	0 0	127 8.68
Comp Req & Same maj	49 71.0	406 37.1	0 0	66 39.3	31 23.5	552 37.7
Comp Req & Sw maj	4 5.80	296 27.1	1 100	45 26.8	0 0	346 23.7
total	69 100	1093 100	1 100	168 100	132 100	1463 100

table contents:
Count
Percent of Column Total

Table 12. Persistence rates per area among students in CHM 113.

CHM 113→115/116	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Pre Med*	*Tech*	*Undclrd*	*total*
Dropped	400 40.5	589 44.9	25 69.4	970 68.8	176 53.3	364 51.6	109 85.8	478 60.4	3111 54.6
Stayed	588 59.5	723 55.1	11 30.6	439 31.2	154 46.7	342 48.4	18 14.2	313 39.6	2588 45.4
total	988 100	1312 100	36 100	1409 100	330 100	706 100	127 100	791 100	5699 100

Table 13. Persistence rates per area among students in CHM 113 whose majors require CHM 115 or CHM 116.

CHM 113→115/116, 115/116 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	94 38.4	384 37.0	0 •	167 53.4	364 51.6	0 •	1009 43.8
Persisted	151 61.6	654 63.0	0 •	146 46.6	342 48.4	0 •	1293 56.2
total	245 100	1038 100	0 100	313 100	706 100	0 100	2302 100

Table 14. Persistence rates per area among students in CHM 113 whose majors require CHM 115 or CHM 116 and who received at least a C in CHM 113.

CHM 113→115/116, 115/116 Required, ≥C in 113	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	50 25.5	178 22.0	0 •	86 37.4	173 34.3	0 •	487 28.0
Persisted	146 74.5	631 78.0	0 •	144 62.6	331 65.7	0 •	1252 72.0
total	196 100	809 100	0 100	230 100	504 100	0 100	1739 100

Table 15. Persistence rates per area among students in CHM 117 whose majors require CHM 118.

CHM 117→118, 118 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	0 •	3 50	0 •	23 30.7	0 •	26 32.1
Persisted	0 •	3 50	0 •	52 69.3	0 •	55 67.9
total	0 100	6 100	0 100	75 100	0 100	81 100

Table 16. Persistence rates per area among students in CHM 117 whose majors require CHM 118 and who received at least a C in CHM 117.

CHM 117→118, 118 Required, ≥C in 113	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	0 •	3 50	0 •	14 21.5	0 •	17 23.9
Persisted	0 •	3 50	0 •	51 78.5	0 •	54 76.1
total	0 100	6 100	0 100	65 100	0 100	71 100

Table 16a. Persistence at ASU of students who stay in or switch to a STEM major that requires CHM 113 and CHM 115/116.

Persistence at ASU (current major)	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Comp Req (Same maj)	114 65.5	607 51.6	0 •	148 46.7	117 56.0	0 •	986 52.5
Comp Req (Sw maj)	22 12.6	433 36.8	0 •	127 40.1	2 0.957	0 •	584 31.1
Drop ASU (Same maj)	36 20.7	112 9.52	0 •	35 11.0	90 43.1	0 •	273 14.5
Drop ASU (Sw maj)	2 1.15	25 2.12	0 •	7 2.21	0 0	0 •	34 1.81
total	174 100	1177 100	0 100	317 100	209 100	0 100	1877 100

Table 17.

PHY 111→112	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Pre Med*	*Tech*	*Undclrd*	*total*
Dropped	231 64.7	532 54.1	12 92.3	729 74.6	77 41.8	61 43.6	16 64.0	228 69.1	1886 62.7
Stayed	126 35.3	451 45.9	1 7.69	248 25.4	107 58.2	79 56.4	9 36.0	102 30.9	1123 37.3
total	357 100	983 100	13 100	977 100	184 100	140 100	25 100	330 100	3009 100

Table 18.

PHY 111→112, 112 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	3 75	67 36.4	0 •	33 50	61 43.6	3 50	167 41.8
Persisted	1 25	117 63.6	0 •	33 50	79 56.4	3 50	233 58.2
total	4 100	184 100	0 100	66 100	140 100	6 100	400 100

Table 19.

PHY 111→112, 112 Required, ≥C in 111	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Pre Med*	*Tech*	*total*
Dropped	2 66.7	32 22.1	0 •	19 37.3	27 26.5	1 33.3	81 26.6
Persisted	1 33.3	113 77.9	0 •	32 62.7	75 73.5	2 66.7	223 73.4
total	3 100	145 100	0 100	51 100	102 100	3 100	304 100

Table 20.

PHY 121→131	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Tech*	*Undclrd*	*total*
Dropped	869 36.5	15 83.3	40 64.5	107 73.8	81 57.0	255 35.9	102 60.7	1469 40.5
Stayed	1509 63.5	3 16.7	22 35.5	38 26.2	61 43.0	455 64.1	66 39.3	2154 59.5
total	2378 100	18 100	62 100	145 100	142 100	710 100	168 100	3623 100

Table 21.

PHY 121→131, 131 Required	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	838 35.7	2 66.7	0 •	19 43.2	107 32.4	966 35.5
Persisted	1509 64.3	1 33.3	0 •	25 56.8	223 67.6	1758 64.5
total	2347 100	3 100	0 100	44 100	330 100	2724 100

Table 22.

PHY 121→131, 131 Required, ≥C in 121	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Dropped	407 22.1	1 50	0 •	9 27.3	55 20.8	472 22.0
Persisted	1438 77.9	1 50	0 •	24 72.7	210 79.2	1673 78.0
total	1845 100	2 100	0 100	33 100	265 100	2145 100

Table 22a. Persistence at ASU of students who stay in or switch to a STEM major that requires PHY 121 and PHY 131.

Persistence at ASU (current major)	*Engr*	*Life Sci*	*Math*	*Phys Sci*	*Tech*	*total*
Comp Req (Same maj)	1140 59.2	2 4.35	0 •	27 34.2	156 61.9	1325 57.5
Comp Req (Sw maj)	295 15.3	21 45.7	0 •	22 27.8	28 11.1	366 15.9
Drop ASU (Same maj)	436 22.6	2 4.35	0 •	13 16.5	53 21.0	504 21.9
Drop ASU (Sw maj)	55 2.86	21 45.7	0 •	17 21.5	15 5.95	108 4.69
total	1926 100	46 100	0 100	79 100	252 100	2303 100

Table 23. Persistence rates to second course per introductory STEM sequence.

All students whose majors require they	*Persist to 2nd Course*	*Persist to 3rd Course*
Calculus	54%	56%
Biology	57%	
Chemistry 113	56%	
Chemistry 117	68%	
Physics 111	58%	
Physics 121	65%	

Table 24. Persistence rates to second course per introductory STEM sequence among students receiving at least a C in current course.

All students who received at least a C in current course and whose majors require they	*Persist to 2nd Course*	*Persist to 3rd Course*
Calculus	67%	69%
Biology	69%	
Chemistry 113	72%	
Chemistry 117	76%	
Physics 111	73%	
Physics 121	78%	

Table 25. Rate at which students drop from ASU per introductory STEM sequence.

STEM Sequence	*Percent of students who have not completed introductory STEM requirements for their current major (no course in past 2 years)*
Calculus	41%
Biology	39%
Chemistry 117	15%
Physics 121	25%

Table 26. Record of switches among students in STEM and non-STEM majors. Includes all students who enrolled in MAT 270. Cell entries are numbers of students in row category who switched to column category, together with percent of row total.

Switches (all students)	*Not STEM Now*	*STEM Now*	*total*
Not STEM Then	1314 70.8	543 29.2	1857 100
STEM Then	1056 21.4	3880 78.6	4936 100
total	2370 34.9	4423 65.1	6793 100

Table 27. Record of switches among students in STEM and non-STEM majors. Includes all students who enrolled in MAT 270 and who did not drop from ASU. Cell entries are numbers of students in row category who switched to column category, together with percent of row total.

Switches, Not Dropped	*Not STEM Now*	*STEM Now*	*total*
Not STEM Then	1314 76.0	414 24.0	1728 100
STEM Then	1056 31.5	2298 68.5	3354 100
total	2370 46.6	2712 53.4	5082 100

Table 28. Record of switches among students in STEM and non-STEM majors. Includes all students who enrolled in MAT 270, who received at least a C in MAT 270, and who did not drop from ASU.

Switches, Not Dropped ≥ C in MAT 270	*Not STEM Now*	*STEM Now*	*total*
Not STEM Then	677 70.6	282 29.4	959 100
STEM Then	574 30.9	1286 69.1	1860 100
total	1251 44.4	1568 55.6	2819 100

Table 29. Record of switches among majors by students who enrolled in MAT 270 and who did not drop from ASU. Row majors are at the time of taking MAT 270; column majors are as of May, 2007.

Switches, Not Dropped	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Pre Med*	*Tech*	*Undclrd*	*total*
Engr	1258 61.2	93 4.53	28 1.36	536 26.1	31 1.51	0 0	34 1.65	75 3.65	2055 100
Life Sci	7 5.19	92 68.1	0 0	27 20	3 2.22	0 0	1 0.741	5 3.70	135 100
Math	6 3.11	3 1.55	96 49.7	82 42.5	2 1.04	0 0	0 0	4 2.07	193 100
Not STEM	20 2.64	18 2.38	19 2.51	657 86.8	11 1.45	0 0	12 1.59	20 2.64	757 100
Phys Sci	7 2.13	30 9.12	7 2.13	96 29.2	181 55.0	0 0	1 0.304	7 2.13	329 100
Pre Med	3 2.19	25 18.2	2 1.46	40 29.2	22 16.1	40 29.2	1 0.730	4 2.92	137 100
Tech	47 7.32	8 1.25	14 2.18	202 31.5	5 0.779	0 0	344 53.6	22 3.43	642 100
Undclrd	106 12.7	74 8.87	38 4.56	316 37.9	35 4.20	0 0	28 3.36	237 28.4	834 100
total	1454 28.6	343 6.75	204 4.01	1956 38.5	290 5.71	40 0.787	421 8.28	374 7.36	5082 100

Table 30. Record of switches among majors by students who enrolled in MAT 270, who did not drop from ASU, and who received at least a C in MAT 270. Row majors are at the time of taking MAT 270; column majors are as of May, 2007.

Switches, Not dropped, ≥ C	*Engr*	*Life Sci*	*Math*	*Not STEM*	*Phys Sci*	*Pre Med*	*Tech*	*Undclrd*	*total*
Engr	694 61.5	64 5.67	9 0.797	293 26.0	15 1.33	0 0	19 1.68	35 3.10	1129 100
Life Sci	5 5.21	70 72.9	0 0	15 15.6	2 2.08	0 0	1 1.04	3 3.12	96 100
Math	1 1.22	3 3.66	29 35.4	45 54.9	2 2.44	0 0	0 0	2 2.44	82 100
Not STEM	13 3.21	12 2.96	9 2.22	340 84.0	5 1.23	0 0	11 2.72	15 3.70	405 100
Phys Sci	2 1.03	24 12.4	3 1.55	54 27.8	105 54.1	0 0	1 0.515	5 2.58	194 100
Pre Med	0 0	23 28.4	1 1.23	21 25.9	14 17.3	20 24.7	0 0	2 2.47	81 100
Tech	28 7.80	7 1.95	7 1.95	113 31.5	5 1.39	0 0	190 52.9	9 2.51	359 100
Undclrd	78 16.5	54 11.4	20 4.23	193 40.8	25 5.29	0 0	17 3.59	86 18.2	473 100
total	821 29.1	257 9.12	78 2.77	1074 38.1	173 6.14	20 0.709	239 8.48	157 5.57	2819 100

Table 31. Record of switches among students in STEM and non-STEM majors. Includes all students who enrolled in BIO 187. Cell entries are numbers of students in row category who switched to column category, together with percent of row total.

Switched (Bio)	*Not STEM Now*	*STEM Now*	*total*
Not STEM Then	1397 76.2	437 23.8	1834 100
STEM Then	342 22.5	1177 77.5	1519 100
total	1739 51.9	1614 48.1	3353 100

*Table 32. Academic and Career Advising (*Scale: 5=High, 4=Moderately High, 3=Moderate, 2=Moderately Low, 1=Low)*

Survey Item	*STEM*	*New Major*	*Difference*	*p-value ≤ 0.05*
Q3 Quality of Advising	2.72*	3.88	1.16	.000
Q22 Satisfaction with career counseling	2.38	3.60	1.21	.000
Q26 Had adequate advising or help with academics (faculty)	2.77	3.43	0.68	.000
Q6 Career options worth the effort to get the degree	3.25	4.34	1.09	.000

Table 33. Structure, Curriculum, and Culture

Survey Item	*STEM*	*New Major*	*Difference*	*p-value ≤ 0.05*
Q8 I had conceptual difficulties with subjects	3.00	1.97	1.03	.000
Q15 I had problems related to class size	2.68	1.86	0.82	.000
Q14 I had poor recitation support by TAs	2.97	1.76	1.21	.000
Q12 Experienced low morale due to the competitive culture	2.65	1.78	0.86	.000
Q18 I had peer support in my major	2.75	4.06	1.31	.000

Table 34. Faculty and Teaching Assistants

Survey Item	*STEM*	*New Major*	*Difference*	*p-value ≤ 0.05*
Q19 Faculty are approachable	2.70	4.32	1.62	.000
Q2 Quality of instructors	3.05	4.28	1.23	.000
Q13 Had language difficulties with international faculty/TAs	3.29	1.69	1.60	.000
Q24 Had research opportunities with faculty	1.99	3.26	1.27	.000

Table 35. Work, study, and Engineering

Survey Item	*ENGR*	*New Major*	*Difference*	*p-value ≤ 0.05*
Q21 Difficulty balancing work and the course load in FSE	2.88	2.37	0.51	
Q11 Expect the degree to take more than 4 years to complete	3.68	2.81	0.87	.000
Q27 Outside job made it difficult to complete the degree	2.37	1.93	0.43	

Table 36. High School Preparation

Survey Item	*Old*	*New Major*	*Difference*	*p-value ≤ 0.05*
Q9 Had adequate high school preparation for major (non-engineering STEM)	3.89	3.29	0.60	.000
Q9 Had adequate high school preparation for major (engineering)	3.49	3.82	-0.63	.000

Table 37. GPA STEM and New Major

Area	% Below 2.0 GPA	% Above 2.0 GPA	% Above 3.0 GPA	Mean
Engr	17%	39%	44%	2.74
Engr NEW	1%	40%	59%	3.08
Non-Engr STEM	7%	35%	58%	3.01
Non-Engr NEW	2%	28%	70%	3.23

Table 38. Classification of test items in introductory STEM courses according to Bloom's taxonomy. Cell entries are percents of the number of a test's items that fit the column category.

Course	*Knowledge*	*Comprehension*	*Application*	*Analysis*	*Synthesis*	*Evaluation*
BIO 1	24%	28%	33%	15%	-	-
BIO 2	91%	-	7%	2%	-	-
BIO 3	91%	9%	-	-	-	-
BIO 4	73%	17%	7%	3%	-	-
CHM 1	44%	20%	4%	28%	4%	-
CHM 2	24%	40%	20%	16%	-	-
CHM 3	32%	12%	48%	8%	-	-
CHM 4	44%	16%	36%	4%	-	-
CHM 5	60%	28%	8%	4%	-	-
CHM 6	29%	29%	14%	14%	-	14%
CHM 7	52%	4%	40%	4%	-	-
CHM 8	32%	37%	32%	-	-	-
CHM 9	24%	48%	12%	16%	-	-
CHM 10	48%	16%	28%	8%	-	-
ENG 1	-	-	56%	22%	11%	11%
MAT 1	74%	26%	-	-	-	-
MAT 2	88%	13%	-	-	-	-
MAT 3	50%	50%	-	-	-	-
MAT 4	100%	-	-	-	-	-
MAT 5	85%	15%	-	-	-	-
MAT 6	50%	6%	31%	13%	-	-
MAT 7	8%	-	69%	23%	-	-
MAT 8	63%	11%	26%	-	-	-
MAT 9	71%	14%	10%	5%	-	-
MAT 10	100%	-	-	-	-	-
MAT 11	94%	6%	-	-	-	-
MAT 12	4%	-	61%	36%	-	-
MAT 13	-	-	89%	11%	-	-
MAT 14	17%	33%	33%	17%	-	-
MAT 15	8%	15%	23%	38%	15%	-
MAT 16	69%	23%	-	8%	-	-
MAT 17	26%	-	53%	21%	-	-
PHY 1	-	44%	56%	-	-	-
PHY 2	-	8%	46%	46%	-	-
PHY 3	3%	50%	28%	20%	-	-

Table 39. SAT-Q scores per area for students who started calculus with the first course (MAT 270).

Group	*Total Cases*	*Count*	*Mean*	*Median*	*StdDev*	*Min*	*Max*
Engr	2999	1588	593.6	600	72.86	350	800
Life Sci	157	89	582.1	580	96.65	320	800
Math	250	97	589.1	580	72.00	390	740
Not STEM	780	453	598.1	600	73.76	350	800
Phys Sci	513	282	593.3	600	76.51	300	780
Pre Med	148	99	581.8	580	76.28	370	740
Tech	1017	562	598.0	600	75.45	330	800
Undclrd	929	562	591.3	600	75.63	350	790

Table 40. SAT-Q scores per area for students who started calculus with the second course (MAT 271).

Group	Total Cases	Count	Mean	Median	StdDev	Min	Max
Engr	2999	469	642.6	650	72.58	390	800
Life Sci	157	24	671.3	670	77.76	450	800
Math	250	51	641.8	650	79.37	460	800
Not STEM	780	130	663.8	660	66.52	470	800
Phys Sci	513	74	631.6	650	96.22	400	800
Pre Med	148	20	652.0	650	61.35	510	770
Tech	1017	124	645.2	650	77.66	410	790
Undclrd	929	129	658.5	660	69.68	460	800

Table 41. Scheffé comparisons with p-values less than 0.20 among comparisons of students' SAT-Q percentile ranks relative to ASU drop rates. Comparisons restricted to students whose current major requires 2 or 3 semesters of calculus and who took MAT 270 prior to Spring 2006 (3 semester required) or prior to Fall 2006 (2 semesters required).

Comparison	Difference	std. err.	Prob
85-89%ile - 00-39%ile	-0.127	0.027	0.042
90-94%ile - 00-39%ile	-0.195	0.029	0.000
90-94%ile - 45-49%ile	-0.247	0.051	0.021
90-94%ile - 55-59%ile	-0.215	0.044	0.021
90-94%ile - 65-69%ile	-0.189	0.040	0.036
90-94%ile - 70-74%ile	-0.209	0.040	0.008
95-99%ile - 00-39%ile	-0.291	0.033	0.000
95-99%ile - 40-44%ile	-0.390	0.085	0.052
95-99%ile - 45-49%ile	-0.343	0.053	0.000
95-99%ile - 50-54%ile	-0.362	0.069	0.007
95-99%ile - 55-59%ile	-0.311	0.046	0.000
95-99%ile - 60-64%ile	-0.289	0.060	0.025
95-99%ile - 65-69%ile	-0.285	0.043	0.000
95-99%ile - 70-74%ile	-0.305	0.043	0.000
95-99%ile - 75-79%ile	-0.251	0.042	0.000
95-99%ile - 80-84%ile	-0.197	0.042	0.042
95-99%ile - 85-89%ile	-0.165	0.037	0.075

Table 42. ANOVA of ASU Drop Rate versus (Start 271 or 272)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	702.421	702.421	3273.5	≤ 0.0001
Strt>1	1	116.213	116.213	541.59	≤ 0.0001
Error	3702	794.366	0.214577		
Total	3703	910.579			

Table 43. Cell Means of ASU Drop Rate on (Start 271 or 272)

Level of Strt>1	Cell Mean	Cell Count
Strt 270	0.5611	2465
Strt 271/272	0.1856	1239

Table 44. Distribution of grades for students who continued to calculus after taking MAT 170.

Grade	*Count*	*Percent*
A	733	25.8
B	811	28.6
C	784	27.6
D	167	5.9
E	343	12.1

Table 45. Calculus grades of MAT 170 students per STEM area of declared major at time of taking MAT 170. Calculus grade is from MAT 210, MAT 251, or MAT 270 depending on in which course student enrolled after completing MAT 170. Cell entries are numbers of students and percents of row totals.

Calculus grade by major area of MAT 170 students	*A*	*B*	*C*	*D*	*E*	*No Calc*	*total*
Engr	82 8.0	145 14.2	182 17.9	40 3.9	71 7.0	499 49.0	1019 100
Life Sci	84 10.8	82 10.5	65 8.3	15 1.9	22 2.8	513 65.7	781 100
Math	11 10.6	13 12.5	11 10.6	1 1.0	6 5.8	62 59.6	104 100
Not STEM	255 8.1	273 8.7	228 7.3	49 1.6	112 3.6	2220 70.8	3137 100
Phys Sci	37 12.5	20 6.7	39 13.1	5 1.7	11 3.7	185 62.3	297 100
Tech	39 8.8	58 13.1	73 16.5	15 3.4	38 8.6	220 49.7	443 100
Undclrd	225 10.4	220 10.2	186 8.6	42 1.9	83 3.8	1407 65.0	2163 100
total	733 9.2	811 10.2	784 9.9	167 2.1	343 4.3	5106 64.3	7944 100

Table 46. Calculus grades of MAT 170 students who received a C or better in MAT 170. Calculus grade is from MAT 210, MAT 251, or MAT 270 depending on in which course student enrolled after completing MAT 170. Cell entries are number of students and percents of row totals.

C or better in MAT 170	*A*	*B*	*C*	*D*	*E*	*No Calc*	*total*
Engr	81 10.0	141 17.5	177 21.9	39 4.8	61 7.6	308 38.2	807 100
Life Sci	84 12.6	82 12.3	61 9.2	13 2.0	15 2.3	410 61.7	781 100
Math	9 11.0	12 14.6	10 12.2	1 1.2	4 4.9	46 56.1	82 100
Not STEM	255 10.1	268 10.6	214 8.5	43 1.7	73 2.9	1676 66.3	2529 100
Phys Sci	36 15.0	20 8.3	36 15.0	5 2.1	10 4.2	133 55.4	240 100
Tech	39 12.1	56 17.4	68 21.2	14 4.4	32 10.0	112 34.9	321 100
Undclrd	222 12.3	217 12.1	175 9.7	36 2.0	71 3.9	1079 59.9	1800 100
total	726 11.3	796 12.4	741 11.5	151 2.3	266 4.1	3764 58.4	6444 100

Table 47. Calculus grades and MAT 170 grades of students who at the time of taking MAT 170 had declared a STEM major that requires at least one semester of calculus. Cells contain numbers of students and percents of row totals.

	Calculus Grade						
MAT 170 Grade	*A*	*B*	*C*	*D*	*E*	*No Calc*	*total*
A	149 23.4	120 18.8	70 11.0	11 1.7	16 2.5	271 42.5	637 100
B	67 8.8	135 17.6	150 19.6	23 3.0	44 5.8	346 45.2	765 100
C	33 4.6	56 7.9	132 18.5	38 5.3	62 8.7	392 55.0	713 100
D	2 1.1	5 2.7	12 6.5	2 1.1	11 5.9	154 82.8	186 100
E	2 0.6	2 0.6	6 1.7	2 0.6	15 4.4	316 92.1	343 100
total	253 9.6	318 12.0	370 14.0	76 2.9	148 5.6	1479 55.9	2644 100

Appendix I
Major Areas Examined by FSIC

Engineering
Aerospace Engineering
Aerospace Engrg (Astronautics)
Bioengineering
Chemical Engineering
Civil Engineering
Civil Engr (Construction Engr)
Civil Engr (Environmental Engr)
Construction
Construction (Gen Bldg Constn)
Construction (Heavy Construtn)
Construction (Resident Cnstr)
Construction (Specialty Constn)
Electrc Engr Tech (Electc Sys)
Electrical Engineering
Engineering
Engr Sci (Matrls Sci Engrg)
Engr Spcl Prgm (Premed Engr)
Industrial Engineering
Materials Engineering
Materials Science & Engr
Mechanical Engineering

Life Sciences
Appl Bio Sci (Appl Bio Sci)
Appl Bio Sci (Ecol Restoration)
Biology
Biology (Biology & Society)
Conservation Biology
Environmental Resources
Kinesiology
Life Sciences
Microbiology
Molecular & Cellular Bio
Molecular Bio Sci/Tech
Plant Bio (Envrnmtl Sci&Ecol)
Plant Bio (Plnt Biochm/Mol Bio)
Plant Biology
Sec Ed (Biological Science)
Speech And Hearing Science

Mathematics
Computational Math Sci
Curr & Inst (Mathematics Educ)
Math (Computnl Math Sci)
Mathematics
Mathematics (Statistics)
Sec Ed (Math/Chemistry)
Sec Ed (Math/Physics)
Sec Ed (Mathematics)

Physical Sciences
Biochemistry
Biochm (Medicinal Chem)
Chem (Environmentl Chm)
Chemistry
Earth And Space Exploration
Geography
Geological Sciences
Geology
Natural Sciences
Physics
Sec Ed (Chemistry)
Sec Ed (Earth/Space Sciences)
Sec Ed (Geography)
Sec Ed (Physics)

Technology
Applied Computing
Comp Engr Tech (Embed Sys Tech)
Comp Engr Tech (Software Tech)
Comp Sys (Embedded Sys Tech)
Comp Sys (Software Tech)
Computer Information Systems
Computer Science
Computer Sys Engr
Manfctrng Engrg Tech
Mech Engr Tech
Mech Engr Tech (Aero)
Mech Engr Tech (Automatn)

Appendix II

Variable Definitions

Database Lookups

SemReq1
Semesters required by student's major at time of taking student's first course.
```
GetCase('SemReq',LookUp('Major',textof('Major1')))
```

SemReq2
Semesters required by student's major at time of running this query.
```
GetCase('SemReq',LookUp('Major',textof('Major2')))
```

MyArea1
Temporary value. Lookup category of major1 in list of STEM majors. Value is "" if not STEM.
```
GetCase(textof('Category'),LookUp('Major',textof('Major1')))
```

MyArea2
Temporary value. Lookup category of major2 in list of STEM majors. Value is "" if not STEM.
```
GetCase(textof('Category'),LookUp('Major',textof('Major2')))
```

Area1
Changes MyArea1 to "Not STEM" if value is "".
```
if(textof('MyArea1')="") then "Not STEM" else 'MyArea1'
```

Area2
Changes MyArea2 to "Not STEM" if value is "".
```
if(textof('MyArea2')="") then "Not STEM" else 'MyArea2'
```

Properties

SameMaj
TRUE if student has same major now and at time of taking first course.
```
textof('Major1')=textof('Major2')
```

STEM1?
TRUE if students' first major is a STEM major. FALSE otherwise.
```
textof('MyArea1')<>""
```

STEM2?
TRUE if students' current major is a STEM major. FALSE otherwise.
```
textof('MyArea2')<>""
```

Strt1
Students who started with the first course
‘Crs1Sem’>0

Strt2
Students who started with the second course (AP, transfer, etc.)
‘Crs1Sem’=0 and ‘Crs2Sem’>0

Strt3
Students who started with the third course (AP, transfer, etc.)
'Crs1Sem'=0 and 'Crs2Sem'=0 and 'Crs3Sem'>0

Pass1Then
1 if student passed the first course in a sequence according to requirements of initial major, 0 if not. (Example is from calculus.)
'Strt2' or 'Strt3' or '270NGr'>(if 'Area1'="Math" then 1 else 0)

Pass2Then
1 if student passed the second course in a sequence according to requirements of initial major, 0 if not. (Example is from calculus.)
'Strt3' or '271NGr'>(if 'Area1'="Math" then 1 else 0)

Pass3Then
1 if student passed the third course in a sequence according to requirements of initial major, 0 if not. (Example is from calculus.)
'272NGr'>(if 'Area1'="Math" then 1 else 0)

NCrsThen
Number of courses passed in this sequence according to student’s first major (example is from biology).
Pass1Then + Pass2Then

Pass1Now
1 if student passed the first course in a sequence according to requirements of current major, 0 if not. (Example is from calculus.)
'Strt2' or 'Strt3' or '270NGr'>(if 'Area2'="Math" then 1 else 0)

Pass2Now
1 if student passed the second course in a sequence according to requirements of current major, 0 if not. (Example is from calculus.)
'Strt3' or '271NGr'>(if 'Area2'="Math" then 1 else 0)

Pass3Now
1 if student passed the third course in a sequence according to requirements of current major, 0 if not. (Example is from calculus.)
'272NGr'>(if 'Area2'="Math" then 1 else 0)

NCrsNow
Number of courses passed in this sequence according to student's current major (example is from biology).
Pass1Now + Pass2Now

SwToSTEM
Major1 is NOT STEM and Major2 is STEM
Not('STEM1?') and 'STEM2?'

SwFrSTEM
Major1 is STEM and Major2 is NOT STEM
'STEM1?' and not ('STEM2?')

StaySTEM
Major1 is STEM, Major2 is STEM, didn't drop
'STEM1?' and 'STEM2?' and not('Dropped')

NevSTEM
Major1 is NOT STEM and Major2 is NOT STEM
Not('STEM1?' or 'STEM2?')

SAT

SAT-Q%
Cutoff scores for ranges of SAT percentile ranks.
if 'SAT-Q'>710 then "95-99%ile" else
if 'SAT-Q'>670 then "90-94%ile" else
if 'SAT-Q'>640 then "85-89%ile" else
if 'SAT-Q'>620 then "80-84%ile" else
if 'SAT-Q'>600 then "75-79%ile" else
if 'SAT-Q'>580 then "70-74%ile" else
if 'SAT-Q'>560 then "65-69%ile" else
if 'SAT-Q'>550 then "60-64%ile" else
if 'SAT-Q'>530 then "55-59%ile" else
if 'SAT-Q'>520 then "50-54%ile" else
if 'SAT-Q'>500 then "45-49%ile" else
if 'SAT-Q'>490 then "40-44%ile" else "00-39%ile"

SAT-T
Total SAT score
'SAT-Q' + 'SAT-V'

Persistence

Prst1

Student started with first course and passed second course. "Pass" means grade greater than E for majors or a grade greater than D for non-majors. (Example is from calculus.)

```
if 'Strt1' and
  'Crs2Sem'>0 and
  'Crs2NGr'>(if textof('Area1')="Math" then 1 else 0)
        then "Persisted" else "Dropped"
```

Persist1N

Numerical version of *Prst1*.

```
if 'Strt1' and
  'Crs2Sem'>0 and
  'Crs2NGr'>(if textof('Area1')="Math" then 1 else 0)
        then 1 else 0
```

Prst2A1

Value is “Persisted” if student enrolled in Course 2, enrolled in course 3, and passed course 3 according to their first major. Value is “Dropped” otherwise. "Pass" means grade greater than E for non-majors or a grade greater than D for majors. (Example is from calculus.)

```
if ('Crs3Sem'>0) and
   ('Crs2Sem'>0) and
   'Crs3NGr'>(if textof('Area1')="Math" then 1 else 0)
  then "Persisted" else "Dropped"
```

Prst2A1N

Value is 1 if student enrolled in Course 2, enrolled in course 3, and passed course 3 according to their first major. Value is 0 otherwise. Student enrolled in Course 2, enrolled in course 3, and passed course 3 according to their first major. "Pass" means grade greater than E for non-majors or a grade greater than D for majors. (Example is from calculus.)

```
if ('Crs3Sem'>0) and
   ('Crs2Sem'>0) and
   'Crs3NGr'>(if textof('Area1')="Math" then 1 else 0)
  then 1 else 0
```

Prst2A2

Value is “Persisted” if student enrolled in Course 2, enrolled in course 3, and passed course 3 according to their current major. Value is “Dropped” otherwise. "Pass" means grade greater than E for non-majors or a grade greater than D for majors. (Example is from calculus.)

```
if ('Crs3Sem'>0) and
   ('Crs2Sem'>0) and
   'Crs3NGr'>(if textof('Area2')="Math" then 1 else 0)
  then "Persisted" else "Dropped"
```

Prst2A2N
Value is 1 if student enrolled in Course 2, enrolled in course 3, and passed course 3 according to their current major. Value is 0 otherwise. "Pass" means grade greater than E for non-majors or a grade greater than D for majors. (Example is from calculus.)

```
if ('Crs3Sem'>0) and
    ('Crs2Sem'>0) and
    'Crs3NGr'>(if textof('Area2')="Math" then 1 else 0)
  then 1 else 0
```

Dropped
Classifies student as completing requirements or dropping from ASU. (Used in combination with a selector variable that selects only those students having sufficient time to complete requirements.)

```
if 'SameMaj'
  then
  if 'NCrsThen'<'SemReq1'
      then "Drop ASU (Same maj)"
      else "Comp Req (Same maj)"
  else
  if 'NCrsNow'<'SemReq2'
     then "Drop ASU (Sw maj)"
     else "Comp Req (Sw maj)"
```

Selector Variables

Definitions of variables used to select subsets of students to which an analysis will apply.

Semesters of Sequence Required (examples from calculus)

SR1=1
1 if student's first major requires 1 semester of sequence, 0 otherwise.
'SemReq1'=1

SR1=2
1 if student's first major requires 2 semesters of sequence, 0 otherwise.
'SemReq1'=2

SR1=3
1 if student's first major requires 2 semesters of sequence, 0 otherwise.
'SemReq1'=3

SR1>1
1 if student's first major requires at least 2 semesters of sequence, 0 otherwise.
'SemReq1'>1

SR2=1
1 if student's current major requires 1 semester of sequence, 0 otherwise.
'SemReq2'=1

SR2=2
1 if student's current major requires 2 semesters of sequence. 0 otherwise.
'SemReq2'=2

SR2=3
Student's current major requires 3 semesters of sequence
'SemReq2'=3

SR2>1
1 if student's current major requires at least 2 semesters of sequence, 0 otherwise.
'SemReq2'>1

Should persist to next course

Students whose major requires that they take the second course and who got at least a C in first course.

Shd2Then
1 if student's original major requires 2nd course and who got at least a C in first course, 0 otherswise.
'SemReq1'>1 and 'Crs1NGr'>1

Shd2Now
1 if student's current major requires 2nd course and who got at least a C in first course, 0 otherwise.
'SemReq2'>1 and 'Crs1NGr'>1

Shd2+
1 if student's original or current major requires 2nd course and student got at least a C in first course, 0 otherwise.
(('SemReq1'>1) or ('SemReq2'>1)) and ('Crs1NGr'>1)

Shd3Then
1 if student's original major requires 3rd course and student got at least a C in second course, 0 otherwise.
'SemReq1'=3 and
'Crs2Sem'>0 and
'Crs2NGr'>1

Shd3Now
1 if student's current major requires 3rd course and student got at least a C in second course, 0 otherwise.
'SemReq2'=3 and
'Crs2Sem'>0 and
'Crs2NGr'>1

Shd3+
1 if student's original or current major requires 3rd course and student got at least a C in second course, 0 otherwise
('SemReq1'=3 or 'SemReq2'=3) and
'Crs2Sem'>0 and
'Crs2NGr'>1

Shd2Sw2STEM
('Shd2Now' and 'SwToSTEM')

Shd3Sw2STEM
('Shd3Now' and 'SwToSTEM')

Appendix III

Reformed Teaching Observation Protocol©

LESSON DESIGN AND IMPLEMENTATION

1) The instructional strategies and activities respected students' prior knowledge and the preconceptions inherent therein.
2) The lesson was designed to engage students as members of a learning community.
3) In this lesson, student exploration preceded formal presentation.
4) The lesson encouraged students to seek and value alternative modes of investigation or problem solving.
5) The focus and direction of the lesson was often determined by ideas originating with students.

CONTENT

Propositional Knowledge

6) The lesson involved fundamental concepts of the subject.
7) The lesson promoted strongly coherent conceptual understanding.
8) The instructor had a solid grasp of the subject matter content inherent in the lesson.
9) Elements of abstraction (i.e., symbolic representations, theory building) were encouraged when it was important to do so.
10) Connections with other content disciplines and/or real world phenomena were explored and valued.

Procedural Knowledge

11) Students used a variety of means (models, drawings, graphs, concrete materials, manipulatives, etc.) to represent phenomena.
12) Students made predictions, estimations and/or hypotheses and devised means for testing them.
13) Students were actively engaged in thought-provoking activity that often involved critical assessment of procedures.
14) Students were reflective about their learning.
15) Intellectual rigor, constructive criticism, and the challenging of ideas were valued.

CLASSROOM CULTURE

Communicative Interactions

16) Students were involved in the communication of their ideas to others using a variety of means and media.
17) The instructor's questions triggered divergent modes of thinking.
18) There was a high proportion of student talk and a significant amount of it occurred between and among students.
19) Student questions and comments often determined the focus and direction of classroom discourse.
20) There was a climate of respect for what others had to say.

Student/Instructor Relationships

21) Active participation of students was encouraged and valued.
22) Students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence.
23) In general, the instructor was patient with students.
24) The instructor acted as a resource person, working to support and enhance student investigations.
25) The metaphor "instructor as listener" was very characteristic of this classroom.

NOTE: Each item is scored on a scale of 0 (“never occurred”) to 4 (“very descriptive”)

Freshman STEM Improvement Committee
RTOP Information for Instructors and Observers

In response to problems of retaining students in STEM majors, the Executive Vice President and Provost appointed the Freshman STEM Improvement Committee to investigate this problem and to make recommendations for future action. An overview of the committee's charge and its plan of action for collecting data are on the opposite side of this sheet.

As stated in the overview, one important part of this plan is to survey the nature of instruction in introductory STEM courses as measure by the Reformed Teaching Observation Protocol (RTOP). That is why we approached you for permission to observe your class. We greatly appreciate your agreement to do this.

The RTOP was created by the Evaluation Facilitation Group (EFG) of the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT). It is an observational instrument designed to measure a lesson's style of instruction. It is designed to be sensitive to instruction that engages students' thinking and that encourages their active participation. Of course, large lectures, by their very nature, are not expected to score highly on the student participation dimension, but the instrument is still sensitive to the lesson's intellectual integrity.

It is worth mentioning that the RTOP is not designed to assess the *quality* of instruction. Rather, it measures the *style* of instruction. The Committee will be very clear in this distinction when it reports results from RTOP observations.

Your observation will be anonymous to the Committee; we will know only the course or courses to which your responses apply. Nora Ramirez, who is coordinating the observations, will assign numbers to each course. The RTOP observer will put that number on his or her observation sheet. The Committee will know only the observation sheet's number. It will not know anything more except that it is, for example, a chemistry course.

Freshman STEM Improvement Committee

Charge from the Provost

- Ascertain the facts relative to the experience of students in ASU's introductory courses in mathematics, engineering, and the sciences
- Derive from these facts a portrait of the current condition of freshman STEM courses at ASU that includes both qualitative data (such as student attitudes and beliefs about STEM subjects) and quantitative data (such as course pass/fail rates)
- Discern and describe the probable causes for high rates of failure and related problems in ASU's freshman STEM courses
- Identify strategies, practices, and programs, and evidence for their success, that other universities nationwide have used to improve outcomes in first-year STEM courses
- Propose a plan of action whereby ASU can become among the top 10 universities in the nation in the success rates of freshman courses in mathematics, engineering, and the sciences

Plan

The committee made this list of variables that focus on students' experiences on which it will collect and examine data:

- Sizes of course sections
- Grade distributions
- Persistence in STEM majors
- Nature of instruction (as measured by RTOP)
- Nature of content (according to Bloom's taxonomy)
- Instructors' thoughts on the courses and on the problems the committee has found
- Student demographics (gender, race, etc)
- Students' mathematics, science, and academic preparation
- Students' feelings and opinions about their STEM courses and about their preparation for them
- Reasons that students who did not continue decided not to continue

Committee

Pat Thompson, Mathematics (Chair)
Carlos Castillo-Chavez, Mathematics
Bob Culbertson, Physics & Astronomy
Alfinio Flores, Education
Ron Greeley, Geology
Susan Haag, Engineering
Tony Lawson, Life Sciences
Ronald Roedel, Engineering
Seth D. Rose, Chemistry & Biochemistry
Ron Rutowski, Life Sciences

Appendix IV

Example Test Items

Classified according to Bloom's Taxonomy of Educational Objectives

Appendix V

Issues that Contribute to Attrition

Academic and Career Advising

Nationwide, undergraduate students in science, math, and engineering education have identified academic advising and career counseling as critical needs that have not been met. Students felt that department advisors should provide accurate advice on academic and career options and on required courses and appropriate sequencing in order to fulfill particular degree requirements (Seymour & Hewitt, 2000). One of the most difficult problems for engineering freshmen was learning how to navigate the complex campus system of advising, counseling, and tutorial services quickly enough in order to prevent problems from escalating (Seymour, 1992a). Students felt advisors provided insufficient information regarding course requirements, special programs, sources of financial help, and career opportunities. Moreover, students perceived advisors as overwhelmed with student load to provide adequate support.

Structure, Curriculum, and Culture

Those who persist and those who do not share similar complaints (Seymour and Hewitt, 2000) Both groups reported poor teaching and difficulty in getting help with academic problems as major issues (90% of switchers and 74% of non-switchers). Large class sizes also contributed to a low quality learning experience and attrition. Introductory STEM courses at the university level are often held in large lecture classrooms in which students may feel isolated and uncomfortable interacting with the instructor Seymour, 1992a). In a longitudinal study of undergraduate women in STEM at the University of Washington, researchers found that both freshmen and sophomore women were most likely to persist if they enjoyed their math and science classes. Freshmen persisters also considered women’s programs (e.g., WISE) and faculty to have a positive influence on them, while sophomore persisters had a positive relationship with an advisor and felt accepted in their department (Brainard & Carlin, 1997).

Faculty

National statistics show science, math, and engineering students are generally dissatisfied with faculty advising and academic support (National Academy of Engineers, 2005, Seymour et al., 2000). Both switchers and non-switchers indicated that advisory systems were poorly organized, with faculty seldom keeping their office hours. In addition, counseling on academic or financial matters was judged to be ineffective. However, faculty intervention often played a large role during a crisis point in the student’s academic or personal life (Seymour, 1992b).

Lack of High School Preparation

Nationally, about 40 percent of STEM switchers and non-switchers reported inadequate high school mathematics and science preparation; undergraduate science students' accounts of under-preparation were broadly of two types: deficiencies of curriculum content and subject depth, and failure to acquire appropriate study skills, habits and attitudes (Seymour, 1992a).

Appendix VI

Best Practices that Contribute to Persistence

By comparing seven undergraduate STEM programs in the Louis Stokes Alliances for Minority Participation (LSAMP), educators identified a key set of features for success: 1) Summer bridge programs, 2) research experience, 3) mentoring, 4) a student center, 5) caring staff, and 6) alliance structure (NSF, 2000). Students received a stipend to attend a 3- to 6-week *summer bridge program* before attending the institution. Courses included math, science, study skills, and time management. The exposure to campus life and the opportunity to meet faculty members and future peers were critical. Peer and research *mentoring* was of great importance to students in their first two years of college. After the freshmen year, *research experience* was identified as most important by a majority of both students and staff; the opportunity to participate in real research was an essential element in promoting persistence.

Engineering Best Practices

Nationally, programs have focused on improving the engineering freshman year by incorporating strategies called for by the NSF and the Accreditation Board (ABET). These include interventions that improve interdisciplinary teaming and communication skills, technology, and design. In 1998, The College of Engineering at the University of Massachusetts Dartmouth launched the Integrated Math, Physics, Undergraduate Laboratory Science, and Engineering (IMPULSE) program. This consisted of *cohort* student groups in a two-semester sequence for engineering and physics majors that integrated mathematics, physics and introduction to engineering (e.g. ASU Foundation Coalition). Outcomes of exams indicated higher levels of conceptual understanding and performance in physics and calculus. The freshman-to-sophomore year attrition rate for IMPULSE students was 17 percent, rather than the typical 40 percent. In 1958, Purdue University instituted their First-Year Engineering Program and it continues to recruit, advise, teach, and retain students for all the schools in Purdue College of Engineering. Since 2000, Purdue has doubled its minority freshmen student enrollment and tripled the Hispanic sub-category with *mentoring* and *tutoring* programs and the opening of a Latino Cultural Center; the number of Hispanic engineering faculty (12) has increased by 140 percent (Purdue, 2006).

University at Buffalo's engineering interventions impact persistence. Strong points include a one-day *orientation* for all incoming freshman, a special *entry level course*, *small group learning* with an instructor in 3 core courses (calculus, chemistry, and physics), and immediate *partnering with faculty* members. The "Opening Day" orientation typically has 30 faculty, 45 student leaders, and representatives from engineering organizations in attendance for approximately 300 incoming freshmen. The entry-level course for all students provides career opportunities and advising. High risk students (admitted below usual standards) have compulsory classes and higher-level monitoring. Buffalo also encourages students to voluntarily meet one hour per week in academic small groups for Chemistry, Calculus, and Physics. The stated objectives of these small groups led by an instructor and a student tutor (with a 10:1 instructor/student ratio) are to increase understanding of the material and a sense of belonging.

Buffalo also assigns each freshman to a faculty mentor. The mentor's role is to be a caring individual who gives students a sense of belonging; in addition, the mentor provides a vision of engineering. Meetings occur as part of course requirements. Over half of the students reported this mentoring experience to be positive. IAFSE has announced its Career Center, opening fall 2007, which will assist students with career advising and industry opportunities. Finally, Buffalo improved course content by requiring defined learning outcomes, criterion referenced grading, and group work. This strategy may assist with issues (IAFSE) associated with lack of peer support and a competitive culture.

Local data identified dissatisfaction with TAs support. TA training is critical, and in the fall of 2007, a new, re-engineered TA training will be offered. We recommend that the TA training include teaching pedagogy, strategies to improve language barriers, and ongoing assessment to monitor and evaluate effectiveness of the TA training and performance.

Engineering Curriculum and Student Climate

To improve engineering curricula, educators call for "a shift to interdisciplinary approaches; more emphasis on the social, environmental, business, and political context of engineering; and emphasis on engineering practice and design throughout the curriculum" (National Academy of Engineers, 2005, p. 105). The NAE recommends that the process of designing, predicting performance, building, and testing be taught from the *first year of college*. They also recommend connecting engineering design and solutions to *real-world problems* (industry case studies). They noted such techniques would attract and retain more diverse students, who often flounder in the standard lecture-style, large-class system. Several programs have incorporated design, building, and testing into freshman curriculum. One example is the Engineering Division of Lafayette College's first-year engineering course (Nesbit et al, 2005). Many programs emphasize the social relevance of engineering, such as Smith College's Picker Engineering Program (Ellis et al., 2005, Grasso et al., 2004). Others have emphasized an *interdisciplinary approach*. Northwestern University's School of Engineering and Applied Science teaches students to develop "sustainable technology, benign manufacturing processes and an expanded array of environmental assessment tools" to maintain both healthy economies and environments (Splitt, 2004).

Personalize Large Classes and Reduce Class Size: Audiences in large classroom settings can be grouped into smaller groups for short episodes of peer discussion and to work on problems, scientific inquiry, and other active exercises. Alternatively, cooperative small group learning situations can be provided during recitation sessions with graduate student teaching assistants to compliment lecture instruction, with an otherwise unchanged lecture and lab pedagogy (Reeve et al., 2004, Seymour, 2001, Swarat et al., 2004). Online courses may use student groups led by a teaching assistant 'coach' as the main vehicle to gain mastery or provide a 'virtual classroom' with student-student and student-faculty computer tele-conferencing (Seymour & Hewitt, 2000). Another option to reduce class size is to offer interdisciplinary one-unit seminars, which provide a more intimate setting for students.

Improve Quality of Graduate Teachers (TA): Often, graduate students have minimal instructional training and consequently, students report poor recitation support by TAs. Jensen et al. (2005) described teaching strategies for TAs. Purdue University has offered a course titled, "Educational Methods in Engineering." In a survey of graduates of the course, data revealed that new professors (those who went on to be professors) reported a significant positive impact on their careers (Wankat & Oreovicz, 2005).

Shift from a Competitive to a Cooperative Educational Model: Often academics regard student attrition as a kind of "natural selection" process; studies reveal that many students who leave the sciences are intelligent and strongly motivated, but are discouraged by the competitive atmosphere (Astin et al., 1985, Astin et al., 1987, Green, 1989, Seymour, 1992). Many (1/3) students switching out of a science, math, or engineering field indicated that a primary reason for leaving was that their morale was undermined by a competitive culture (Seymour, 1992). Accepting attrition as inevitable is both unfair to students and wasteful of resources and faculty time (NAE, 2005). NAE recommended redesigning calculus and physics so motivated students can make connections between subjects to improve social relevance.

Provide cooperative opportunities in introductory classes. Melsa (2005) argued that there is sufficient evidence that learning is enhanced through cooperative experiences. Also, cooperative learning has been endorsed by the National Council of Teachers of Mathematics (1989). In addition to improving academic achievement, critical thinking, self-esteem, and social skills are enhanced (Johnson et al., 2000).

Small Group Learning: Students who learn in small groups demonstrate greater academic performance, express more positive attitudes toward learning, and persist in STEM courses and programs more than their more traditionally taught counterparts (Springer, Stanne, & Donovan, 1999). Small group learning rather than lecture-based instruction impacts academic achievement for members of underrepresented groups and the learning-related attitudes of women and pre-service teachers (Springer et al., 1999, p. 42). Small group learning is often provided with peer educators. A review of colleges in the United States found that over 75% of all higher education institutions utilize peer educators (Ender & Newton, 2000). Most Women in Science and Engineering (WISE) programs include formal mentoring in which upperclassmen serve as role models for freshmen. These mentors help with homework and ease the college transition (Loftus, 2005).

Enhance problem solving skills with Inquiry: Introductory courses may be designed to be discovery-oriented and explore topics while still teaching the basics (Swarat et al., 2004, Tinto, 1998). Educators call for a conceptual and exploratory-learning curriculum for undergraduates including active and team-based learning (Yuretich, 2004). Kaufman, Felder, and Fuller (2000) provided a method to account for individual effort in cooperative teams. Ingram et al. (2004) created student-centered activities to foster inquiry outside of science laboratory settings. Reeve, Hammond and Bradshaw (2004) initiated research workshops for students to practice formulating research questions and experimental protocols. Vivas and Allada (2006) described thematic case-based learning to integrate engineering course content with industry context. Others have summarized methods to engage students, and provided recommendations regarding cooperative and problem-based learning, (Smith, Sheppard, Johnson, and Johnson, 2005)

Improve STEM Student Climate with Summer Programs, Cohorts, Peer Mentors, and Housing

The following programs improve learning climate and social integration for participants during the first crucial year of enrollment. The more integrated a student is in the social activities of a campus environment, the more likely the student is to persist in college (West, 1991). Four types of programs are: summer programs, cohort groups, assigning peer mentors, and designating residence halls. First, a popular community-building experience is the *summer program*. Increasingly all freshmen are invited to attend classes for several weeks as a college orientation. Loftus (2005) cited several examples, such as Syracuse's retention program, which raised the four-year graduation rate within the college of engineering and computer science 10 percent overall and 18 percent for females. Additionally, after the freshman summer program at Virginia Tech was implemented in 1997, the below 30 percent graduation rate of African American and Hispanic engineering students rose to over 50 percent.

Second, schools build community by creating learning cohorts who are enrolled in the same classes each semester. Texas A&M has over 15 groups of 100 freshmen who learn together in sections of calculus, chemistry, and physics. Learning in cohort groups was found to be especially valuable for students transitioning to a large university setting (Loftus, 2005). Tinto (1998) reported that at the University of Oregon and the University of Washington, student cohorts may attend classes with 300 other students, but stay together for small discussion sections of up to 30 students. Tinto noted that students in these learning communities create their own peer groups which support them both academically and socially.

Third, the use of *peer educators* impacts the learning atmosphere. Evaluation of US colleges found that approximately 80 percent of all higher education institutions utilize peer educators (Ender & Newton, 2000). A meta-analysis found peer mediated small-group learning in STEM programs to be highly effective in learning and retention (Springer et al., 1999). Northwestern's peer-facilitated science workshop resulted in higher retention, particularly for minority students (Swarat et al., 2004). STEM WISE programs include mentoring, where upperclassmen serve as role models. Female mentors help with homework and serve as role models during the freshman year (Loftus, 2005). A fourth method to build community is designating *residential communities* or floors for students in a particular major. Some benefits include increased opportunities for teamwork and peer mentoring (Loftus, 2005).

Faculty: Improve Instruction with "A Perfect 10"

In a recent Prism article, authors recommended ten proven steps to improve quality of instruction and approachability for engineering faculty (Wankat & Oreovicz, 2004). These recommendations are condensed below.

1. Provide a list of educational objectives.
2. Teach inductively with simple examples.
3. Divide lecture time with activity intervals.
4. Break class into small groups to practice active learning.
5. Share enthusiasm and explain topic relevance.
6. Learn names of students.
7. Come early and stay late for lectures.
8. Encourage study groups for homework assignments.
9. Reduce time pressure on examinations.
10. Obtain written suggestions from students to improve learning; then initiate several.

Initiating the "Perfect 10" would be beneficial for both underrepresented students and women who thrive in classes with a variety of project-based activities that require teamwork. At the University of Michigan, students in an Engineering 100 section build a greenhouse for nonprofit groups (Alper, 1993). At Alverno College, an all women's college in Milwaukee, science classes, particularly the introductory ones, have used collaboration, which boosted students' self-confidence (Alper, 1993). Literature shows that females believe they have less chance of success (National Research Council, 2006; Rosati & Becker, 2004) and are feel they are low performers when they receive one bad exam grade. Subsequently they may make important decisions, such as changing majors, based on an inaccurate appraisal of their performance.

Provide Research Opportunities

Hadgraft (1998) found increased student motivation and productivity when engaged in a research mission. Working with a faculty member or other researcher allows students to find mentors and gain insight into what science is all about (Gafney, 2005, Nagda et al., 1998). Also, as a research mentor noted, "The work habits required for success in research can carry over and help students in their class work--things like good time management, careful note taking, and the ability to discern the more substantive issues of a problem" (Gafney, 2005, p. 54). Nagda et al. (1998) studied how participation in undergraduate student-faculty research partnerships, which included peer advising, affected retention. In a five-year period at University of Michigan's College of Literature, Science and the Arts, participants in research partnerships had an attrition rate of 11.4% compared to a 23.5% rate for non-participants. According to their data, participation effect was strongest for sophomores and African American students. These authors noted that such research projects successfully combine the educational and research missions of an institution.

Mathematics Best Practices

In 1983 the University of Arizona's mathematics department initiated a self study due to attrition rates reaching 50% in some beginning courses. After initial assessment of its undergraduate education, mathematics department initiated a five year implementation plan to address the problems, based on five premises:

1. Students must be placed in courses commensurate with their abilities
2. Students must be provided with a supportive learning environment and a caring instructor committed to undergraduate education
3. Entry level courses must be structured to meet current student needs
4. Future success of the program relies on effective outreach programs to local schools
5. Students need exposure to technology to enhance the learning experience

The Entry Level Committee's action plan included the following key recommendations: 1) reduce class size; 2) institute a mandatory math placement and advising program; 3) institute a new pre-calculus course; 4) offer a calculus I course with five credit hours; and replace the self-study intermediate and college algebra courses with a two semester sequence in college algebra taught in small classes. The findings of the review committees combined with the above action plan began the process of change in 1985, which over twelve years resulted in a dramatic improvement of the educational environment. The University hired a dozen new faculty members, instituted a Mathematics Center with computer facilities and special services, and augmented the budget to improve undergraduate education. Changes were spearheaded by administration, faculty, and lecturers. In 1997, all freshman level mathematic courses were taught in classes of size 35, with passing rates improved by up to 40%. The mathematics department had excellent relations with other University departments, high schools, and with the local community college. The Math department became a national leader in calculus and differential equation reform and technology usage. The number of mathematics majors dramatically increased.

Elias Toubassi (UA Department of Mathematics) listed aspects of a successful program:

Broad faculty involvement

General departmental support

University encouragement and support for faculty

Regular communication with other university departments

A mandatory mathematics placement test

Careful teaching assignments

Augmentation with instructors dedicated to teaching

Open dialogue and development of joint programs with local school districts and community colleges

Assessment of curriculum and goals for each course

Development of an effective training program for graduate teaching assistants

Reward faculty for contributions to the undergraduate program

Adequate staff support

Toubassi, Elias, Department Goals and Assessment, Recovered on 4/16/07 from online source http://www.maa.org/saum/maanotes49/61.html

Science and Mathematics Best Practices

Calls for instructional reform in the sciences and in mathematics have appeared in documents such as *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*, National Science Foundation (1996); *The Liberal Art of Education: Agenda for Action*, American Association for the Advancement of Science (1990); *Crossroads in Mathematics: Standards for Introductory Mathematics Before Calculus*, American Mathematical Association of Two-Year Colleges (1995); and *Before It's Too Late: A Report to the Nation*, National Commission on Mathematics and Science Teaching for the 21st Century (2000). The primary goal of reform efforts based on these documents has been to improve undergraduate science and mathematics instruction at institutions such as Arizona State University. The reformed efforts are often based n the principles of effective teaching introduced by the American Association for the Advancement of Science (1989). A list of these principles appears in Table 1. In turn, the teaching principles are based on learning theory derived from years of educational and psychological research. That theory posits that effective learning is active, learner-centered, and inquiry-oriented. Such learning enables students to construct new concepts and conceptual systems by connecting new information and concepts to what they already know. Further, such learning often requires restructuring, or even discarding, previous concepts and beliefs when they prove incompatible with or contradictory to new evidence and new concepts (e.g., Alexander & Murphy, 1999). The following is from *Principles of Effective Teaching* (*Science for All Americans, AAAS*, 1989).

Teaching Should be Consistent with the Nature of Scientific Inquiry:

Start with questions about nature.

Engage students actively.

Concentrate on the collection and use of evidence.

Provide historical perspectives.

Insist on clear expression.

Use a team approach.

Do not separate knowing from finding out.

Deemphasize the memorization of technical vocabulary.

Teaching Should Reflect Scientific Values:

Welcome curiosity.

Reward creativity.

Encourage a spirit of healthy questioning.

Avoid dogmatism.

Promote aesthetic responses.

Teaching Should Aim to Counteract Learning Anxieties:

Build on success.

Provide abundant experience in using tools.

Support the role of girls, women and minorities in science.

Emphasize group learning.

Science Teaching Should Extend Beyond the School

Teaching Should Take Its Time

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