2018

Failure Rates in Engineering: Does It Have to Do with Class Size?

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Abstract
Not everyone is meant to be an engineer, but more could be. The failure rate for engineering students is unparalleled. A staggering 40% of students in engineering do not make it through the first year and of those who make it, 30% would fail in many of its fundamental courses. Engineering is not, nor should it be, an easy program. Traditionally, many researchers have argued that the primary reason why students fail in these courses is a lack of preparedness for the high level of academic rigors in engineering. They have also argued that beyond the rigors of the material is the time commitment required outside of the classroom. While the average college course requires 2 hours of outside study for every one hour in the classroom, engineering courses require an estimated 4 hours. In addition, engineering instructors more extensively employ extensive lecturing in their classroom and grade on a curve, two practices that create educational disadvantages for engineering students. Although the systems in place that run many engineering colleges around the country work fairly well for the traditional engineering student—the teenager who shows up on campus ready to dedicate the next four years of their lives to school, a chunk of undergraduates in commuter schools do not fit this profile. These students are juggling classes and a job or family or both. Most of our education system is not built to cater to their needs, and its results are extremely wasteful.

This paper presents initial results of a research project on failure rates in an engineering commuter school—where 40% of our students work more than 10 hours per week while going to school full time. We focused on 3 fundamental engineering courses: mechanics of materials, dynamics, and introduction to circuit. This pilot research is addressing the question of “What do failure rates in these courses really measure?”

Disciplines
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Comments

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Failure Rates in Engineering: Does It Have to Do with Class Size?

Dr. Peggy C. Boylan-Ashraf, San Jose State University

Dr. Peggy C. Boylan-Ashraf is an Assistant Professor in General Engineering at San Jose State University. She teaches structures courses and researches on new paradigms in teaching introductory solid mechanics courses with an emphasis on large enrollments. Over her years of teaching, Dr. Boylan-Ashraf has taught over 6,500 students and has been awarded numerous teaching awards by her students, department, and college.

Mr. John R. Haughery, Iowa State University
Failure rates in engineering – does it have to do with class size?

ABSTRACT

Not everyone is meant to be an engineer, but more could be. The failure rate for engineering students is unparalleled at San Jose State University. A staggering 40% of students in engineering do not make it through the first year and of those who make it, 30% would fail in many of its fundamental courses. Engineering is not, nor should it be, an easy program. Traditionally, many researchers have argued that the primary reason why students fail in these courses is a lack of preparedness for the high level of academic rigors in engineering. While the average college course requires 2 hours of outside study for every one hour in the classroom, engineering courses require an estimated 4 hours. Although the systems in place that run many engineering colleges around the country work fairly well for the traditional engineering student – the teenager who shows up on campus ready to dedicate the next four years of their lives to school, a chunk of undergraduates in commuter schools, such as SJSU, do not fit this profile. These students are juggling classes and a job or family or both. Most of our education system is not built to cater to their needs, and its results are extremely wasteful.

This paper presents initial results of a research project on failure rates in the college of engineering at SJSU, where 40% of our students work more than 10 hours per week while going to school full time. We focused on 3 fundamental engineering courses: mechanics of materials, dynamics, and introduction to circuit. This pilot research is addressing the question of "What do failure rates in these courses really measure?"
INTRODUCTION

Engineering has greatly impacted the world since the dawn of time and the quality of life of humanity is highly dependent upon the quality of engineering design and development -- making the education of its students of great importance. Due to the dynamic nature of engineering, the education of these students should include strong fundamentals as well as the establishment of the desire of life-long learning\textsuperscript{28}. Most engineering educators would agree that educating future engineers in a strong knowledge of fundamentals is no trivial goal; and the task becomes more profound when educating students in large lectures\textsuperscript{31,59}.

Due to budget pressures and the attractive possibility for cost reduction, numerous commuter schools in general, including SJSU, have chosen the route of teaching fundamental classes in large lectures\textsuperscript{10,42,27,54}. As in any debatable topic, the discussion of large lectures has birthed two schools of thoughts. Christopher’s\textsuperscript{12} study found the following:

1. The proponents of large lectures argue that large lecture classes generate the numbers, which provide other faculty the opportunity to teach special topic undergraduate and graduate classes that might not otherwise be offered to the student body due to budget and other resource constraints.

2. The opponents of the large lecture approach argue that large lecture sections dilute the learning process, place an undue burden on faculty in terms of test monitoring, grading, office hours or student interaction, and course management.

Whichever camp one belongs to, whether one attempts to move toward small lectures or large ones, or one believes more in one idea over the other, there is a perspective that has been long neglected – the students. The central issue is not small versus large lectures, but the effectiveness of student learning.

It is quite true that in large fundamental courses, such as mechanics of materials, dynamics, and introduction to circuit where a lecture hall could fit as many as 40 to 400 students or more, a very different set of challenges is faced. Faculty teaching these courses with large numbers of students will likely list many of the same types of challenges; among them are: organization of paperwork, management of distractions, anonymity of the students, lack of flexibility in class activities, and diverse background and preparation of the students\textsuperscript{10,27,36}. Likewise, issues for students arise when one is enrolled in courses with hundreds of other peers; among them are: impersonal atmosphere, minimal contact with faculty, getting “lost in the crowd”, low motivation and minimal involvement, and shallowness of understanding\textsuperscript{42,85}. Whether as a faculty or as a student in a large lecture, numerous studies\textsuperscript{2,17,21,27,75} have shown over many decades that the quality of education in a large lecture class is not equivalent to that in smaller classes.

PROBLEM STATEMENT

Increasing student involvement through making greater use of active modes of teaching was the major recommendation of the National Institute of Education report about 30 years ago in 1984 as stated in Involvement in Learning: Realizing the Potential of American Higher Education\textsuperscript{73}. Since that time, many learning theorists, faculty development consultants, and reports on higher education have recommended the importance of interactive and participatory student involvement for learning that effects cognitive and effective growth – and literally
hundreds of articles have been written on the topic since that report. Yet despite these recommendations, college and university professors continue to lecture – and in some cases, in lecture halls with hundreds and hundreds of students\textsuperscript{36}. Part of this is due to the lure of economies of scale, which refers to the cost advantages that an enterprise obtains due to expansion\textsuperscript{54}. The lecture format is still dominant in many universities and has become the quick and convenient cost-cutting strategy\textsuperscript{42}. “Large classes are very prevalent in many universities and are often gateway courses to students’ major fields of study”\textsuperscript{70}, and in engineering, its introductory fundamental courses such as mechanics of materials, dynamics, and introduction to circuit are easy targets of the practice of “herding” students into large classes. This practice can pose quite a difficult adjustment for freshman and sophomore college students.

Cooper and Robinson\textsuperscript{14} artfully expressed the potentially dangerous consequence of subjecting freshman and sophomore college students to large lecture classes:

A growing body of research points to the value of undergraduate learning environments that set high expectations, promote active and interactive learning, and give students personal validation and frequent feedback on their work. These settings and practices are especially beneficial for beginning learners as they make the transition to college. Yet in most universities, introductory courses that fulfill their curriculum requirements often carry enrollment of hundreds of students. These large-class settings have historically been heavy lectured-centered, requiring minimal student engagement and expecting little more than memorization of terms and concepts as evidence of student learning. The sheer size and anonymity of large classes seem to weigh against the very elements that promote students’ involvement and intellectual development, learning, and success. Inattention or absence from class and mediocre student performance seem to be tolerated simply as unfortunate realities\textsuperscript{14}.

Although the 3 large fundamental engineering courses in this study pose a different set of issues, which often implies that quality teaching is not possible in large classes, researchers in education\textsuperscript{10,42,54,75} suggested the contrary – quality teaching is quite possible in large classes while focusing on student-centered, cooperative, active experimentation, and high-level thinking learning, instead of the traditional teacher-centered, individual, reflective observation, and routine-drill learning.

Almost 2 decades ago, Felder\textsuperscript{23} had recommended the need to change the pedagogy used in engineering classrooms. According to his study at that time, many engineering classes in 1999 were taught in exactly the same way that engineering classes in 1959 were taught and that the existing teaching and learning strategies in engineering programs were outdated and needed to become more student-centered\textsuperscript{23}. Even today, almost 20 years later, the paradigm of engineering education is still essentially the same in the college of engineering at SJSU and the need to identify an effective and affordable teaching approach applicable for large fundamental engineering courses still exists. Other researchers\textsuperscript{31,45,52} echo Felder and suggested that the overall goal for a new paradigm is for students to learn and apply a systems approach to engineering problem solving such that when they become practicing engineers they will develop more sustainable solutions.
THE PURPOSE OF THE STUDY

The purpose of this study is to compare preparations in the engineering curriculum, particularly courses taught in community colleges versus those being taught within the university—the emphasis is on 3 fundamental engineering courses at SJSU: mechanics of materials, dynamics, and introduction to circuit. All these courses have been traditionally-taught and instruction primarily focuses on verbal and printed words, rote memorization, and is lecture driven. Students are told what they are expected to know and concepts are presented deductively. Instructors conduct lessons by introducing and explaining concepts to students, and then expect students to complete tasks to practice the concepts. This paper presents preliminary analysis of the study of comparisons of prerequisite courses for the above aforementioned fundamental engineering courses taken in community colleges versus within the university. The first-year retention rate at SJSU is 86.1% (Fall 2014 entering freshmen) and the 6-year graduation rate is only 56.1% (Fall 2009 entering freshmen). While the 6-year graduation rates at its college of engineering are disappointing for Asian students (62.6%) and White students (59.4%), the 6-year graduation rates for African American (40.4%) and Latino/a (44.2%) students (Fall 2009 entering freshmen) are truly unacceptable. SJSU has many innovative initiatives and institutional efforts to support student success and inclusive excellence; however, many of these efforts focus on improving student services and technology/infrastructure rather than addressing classroom pedagogies, particularly techniques to teaching large classrooms. The following factors will be investigated in the study as a whole: socioeconomic background, health issue, work load versus course load, enthusiasm in engineering, learning environment and confidence in pre-engineering courses, and interaction with instructor. However, this paper focuses on whether taking prerequisite courses at community college is academically more beneficial for the students than taking them within the university. The main difference being class size.

RESEARCH QUESTIONS

The research questions explored in this preliminary analysis of our study are:
1. What factors contribute to failure rate in mechanics of materials, dynamics, and introduction to circuit in SJSU?
2. Does taking prerequisite courses at community college versus SJSU influence the outcome of the target courses?

SIGNIFICANCE OF THE STUDY

As part of a broad effort to improve engineering education, this study will serve as an important piece in understanding ways to promote better understanding of effective teaching and the dynamics of student learning, especially in large fundamental engineering classes in the college of engineering at SJSU. While in general it has been shown that intervention or reform style teaching improves academic achievement over traditional lecture-based styles\cite{1,59,88}, this study will be among the first to demonstrate an investigation that is specifically tailored to large
fundamental engineering classes, particularly mechanics of materials, dynamics, and introduction to circuit in SJSU.

LITERATURE REVIEW

Higher education in the U.S. has many ironies. One is that most professors at leading colleges and universities have no formal training in teaching\(^3,22\). Even to this day, most graduate training programs focus on the development of research and scholarly skills rather than skills related to instruction\(^18,50\). As a result, few faculty members have any systematic knowledge or experience in preparing and delivering effective lectures, in leading classroom discussions, or in the mentoring of graduate and undergraduate students\(^8,78\).

A second irony is that while Ph.D. programs at leading research institutions typically emphasize research and other academic scholarship, only a small percentage of the graduates of these programs actually secure faculty positions at research institutions. Instead, a majority of them go to institutions that place much greater emphasis on teaching as part of the faculty member’s roles and responsibilities\(^35\). One consequence for many of these new graduates is that the transition from graduate student to faculty member is difficult. Most learn how to become an effective teacher on the job\(^22\), devoting much if not all of their first few years as a professor to developing courses, designing and redesigning lectures, and learning solutions to the legion of issues students bring to them in their classes\(^8\).

The third irony is perhaps the most peculiar and tragic of the three. Many institutions (and the academic departments within them) ask their least experienced faculty (typically, new assistant professors or lecturers) to teach large courses in their first few years\(^8,22\). Often these courses have many hundreds of students and are, by virtue of their size, among the most challenging to teach effectively\(^13,36,62,48\). Yet many senior faculty members view teaching these courses as a rite of passage, challenges that all faculty members must experience at early points in their careers regardless of their ability or interest. The practice of “giving” these courses to new junior faculty members is unfortunate. More often than not, they have the least amount of knowledge and experience in teaching in the large class setting\(^22,49\).

These ironies plus the massive shift which is occurring in higher education, driven by complex forces including financial, administrative, and organizational and stakeholder expectations are not only changing the world, but has led to the emergence of educators improving and maintain the quality of teaching and learning outcomes while contending with increasing class size. Large classes will continue to be the cultural norm in higher education, despite of mixed evidence on its effectiveness and student outcomes; but they also provide the push for innovative solutions to overcome challenges.

Definition of Large Classes

Although for many years, researchers have studied the effects of class size on teaching effectiveness and student learning, large classes in higher education is a term that has no universally accepted definition; some institutions use the term “large” to refer to classes of more than 40 students\(^15\), while other institutions regard a large class as one with more than 200 students\(^62\).
Challenges and Opportunities of Large Classes

Teaching large classes has its own dynamics for faculty and presents significant challenges in teaching. Many researchers agree that faculty members who teach them describe large classes as a more demanding context for teaching than smaller classes because they require more effort and much greater attention to organization and management. Holding students’ attention in an auditorium is more difficult than in a classroom of 20 students because they are physically distant from the professor. Many aspects of the course must be carefully organized, even scripted, because simple mistakes in lectures, assignments, or exams may confuse hundreds of students, not just a few. Large classes may also require a level of personnel management and supervision that can be extremely time-consuming. Because many instructors of large classes rely heavily on graduate teaching assistants to lead discussion sections and evaluate students’ exams and papers, often faculty members must carefully supervise and assist the teaching assistants, in addition to working with the undergraduates.

For students, large classes offer a different set of challenges. Some students feel anonymous in large classes because they rarely know many of the other students (if any) and the faculty member rarely gets to know them as individuals. Students find this anonymity impersonal and off-putting, particularly students who are used to a smaller and supervised learning environment. Unfortunately, the impersonal quality of large classes is sometimes coupled with limited access to instructional assistance. With very large numbers of students, faculty members and teaching assistants have very limited time to devote to any one individual. As a result, students must learn more independently, relying less heavily on interaction with the instructor and more heavily on their own abilities and interactions with teaching assistants and peers.

Despite these challenges, large classes may provide faculty members and students with unique opportunities for teaching and learning. Given their size, large classes often include a more diverse group of students. Diversity enlivens conversations and discussions, and makes for more interesting learning. Equally gratifying is the faculty member’s sense of wide educational impact in large classes where ideas and materials are studied and learned by many students from very different educational backgrounds and perspectives. Finally, working with teaching assistants in large classes is often quite rewarding. Many faculty members believe that there is little that they do which is more important than training the next generation of professors how to teach effectively. Large classes provide a valuable context for this training.

Many undergraduates thrive on large classes for precisely the same reasons that others dislike them. Some large classes offer a low-pressure context for learning and an opportunity to exercise independence in deciding what and how to learn. Large classes offer greater flexibility in class participation and attendance than small classes. Some students may find this attractive because it enables them to coordinate more effectively their academic and work schedules. Finally, large classes offer nearly limitless opportunities for making contacts with other students, either to study or just to meet.

Learning Theories

Learning theories cannot be divorced from effectiveness of student learning and acts as a general explanation for observations made over time in order to address the challenges of helping learners succeed and to explain and predict behavior. To understand the complex process of learning, in essence, the theory about human learning can be categorized into six
broad paradigms: behaviorism, cognitivism, constructivism, experiential, humanistic, and social-situational learning theories.

Behaviorism is a theory, which concerns the observable change in behavior. Behaviorists believe that learning is provided by change in actions through an explorative process. Behaviorism exposes individuals to external stimuli until a desired response is received. In this theory, knowledge is transferred by the teacher while the learner is a passive participant. Cognitivism emerged when researchers found out that behaviorism did not account for all types of learning. According to this theory, knowledge can be viewed as a scheme, that is, symbolic mental constructions that are organized or processed in the mind. Learning occurs when there is a change in the learner’s schemata; the learner is an active participant. On the other hand, constructivism assumes that learning is a process of constructing knowledge rather than acquiring it. It takes the learner’s social, cultural and contextual conditions into consideration and theorizes that the learner constructs knowledge through experience. In other words, learners interpret new information through their contextual experiences and build on their existing knowledge from the conclusions reached during the assimilation of new knowledge and reflection on it. Experiential learning theory is a holistic perspective on learning that combines experiences, perception, cognition and behavior. It is a continuous process grounded in experience. Humanistic is another theory of learning and priorities for human needs and interests. This theory believes that it is necessary to study the person as a whole, especially as an individual grows and develops over the lifespan. Finally, socio-situational theorists emphasize that learning takes place in social relationships. Out of these six theories of learning, the constructivism theory of learning has often been used as a model to construct a theoretical perspective in engineering education. Out of the six paradigms, researchers believe constructivism aligns best with engineering education. It is a theory of learning founded on the premise that the reflection of our experiences will construct our own understanding of future knowledge, much like the purposeful, deliberate, and systematic nature of engineering, which requires reflection on past knowledge to construct future creations. There are several guiding principles of constructivism:

1. Understanding comes from interactions with the environment. A learner’s knowledge comes from his/her pre-existing knowledge and experience, and new knowledge is formed when connecting previous experience to the new content and environment.
2. Conflict in the mind or puzzlement is the stimulus for learning and determines the organization and nature of what is learned.
3. Knowledge involves social negotiation and the evaluation of the viability of individual understanding.

Elements of Effective Teaching and Learning Using Student-Centered Pedagogy in Large Classes

Although there is no single, best method for addressing the effectiveness of student learning, especially in large classes, at least seven elements of effective teaching, suggested by numerous researchers discussed below, shape how much and how well students learn in this context. The first is careful design and preparation of the course. Course design shapes students’ experiences, the pathways through areas of content and the mechanism by which
material is learned. In the absence of careful design and adequate preparation, students may have great difficulty following the flow of material and course work. This problem is magnified in large courses because a greater number of students is more likely to become confused, particularly since they have limited access to the instructor for individualized assistance in explaining difficult material or in clarifying the relationships between different parts of the course. A second important element to effective learning in large classes is the quality of the instructor’s presentations to students. Whether these are formal lectures, facilitated exercises or laboratories, or interactive conversations, the preparation and delivery of the presentations is critical to students’ perceptions and grasp of the content of the course. Large classes typically rely heavily on some form of lecture or presentation. Separate from other parts of the class, these presentations can either “make or break” learning for hundreds of students. The level of enthusiasm the instructor communicates for the material and the clarity of ideas the instructor delivers will influence whether many students engage the ideas and commit to working hard over the course of the term in studying and learning.

A third aspect of large courses that affects how well students learn is the level of administration and management of the course. Large courses present a host of unique administrative challenges that range from ensuring continuity among discussion sections led by different teaching assistants to those associated with distributing and collecting students’ examinations in a large lecture hall in a timely manner. The challenges are not trivial; they certainly influence how well students perform on many aspects of the course, and when they go wrong are often the subject of students’ vocal complaints. More students will learn the material if the course is well organized and well managed.

Fourth, classes that incorporate some form of active or experiential learning engage students more effectively than classes that do not. The traditional “lecturing/listening” model of teaching is typically less effective because students play a primarily passive role, taking little responsibility for making sense of the content or in applying it to the solution of problems. Obviously, the challenge in large courses is finding mechanisms by which learning can be active and participatory. Traditional interactive exchanges between the instructor and students that may work well in seminars and small classes can rarely be used in classes of much over forty students. In large classes, students may participate in the learning process with one another or in experiences altogether outside of the classroom. In these types of experiences, the professor’s role shifts from lecturer to facilitator, from expositor to coordinator. Collaborative working groups among students, small group discussions in the lecture hall, and experiential learning opportunities remove the students from the role of passive learner, putting him or her in a participatory role.

An increasingly important fifth element of large classes is engaging students through the use of multimedia. For decades instructors have relied on films, photographic images, and transparencies to convey ideas or to offer illustrations. These are particularly important to teaching and to learning in large classes because of the diversity of student experiences and learning preferences. They offer students different “looks” at the material and, at the same time, provide the instructor with pedagogical stimuli that are likely to engage students, particularly those who are visually oriented.

Ensuring that graduate student teaching assistants are adequately prepared and supervised is a sixth element of effective teaching in large classes. Although instructors use teaching assistants differently, many large courses are divided into lecture and recitation sections, with
teaching assistants taking instructional responsibility for the latter. The obvious challenge is that most graduate students have little teaching knowledge and experience. Further, they may have little or no knowledge of the content of the course. Because teaching assistants often spend more time with students individually and in smaller groups than the instructor in a large class, they must receive adequate preparation in course content and in how the material must be taught.

A final element related to how well faculty teach and how well students learn is assessment. To what extent does the instructor incorporate assessment into his/her analysis of the course and student learning? At the heart of this issue is the idea that affective teaching must be informed with knowledge about what students learn and how they learn. In large classes this is particularly challenging because there are few ready mechanisms other than examinations and assignments, for assessing whether students grasp the material or are engaged in the subject. Although exams do shed light on levels of student learning, they are not necessarily informative about the problems students may experience in the course or the precise causes of their problems. Traditional exams and assignments do not necessarily reveal whether the instructor and teaching assistants offer perspectives on the course material that are consistent or complimentary. They also do not necessarily reveal whether poor student performance is the result of inadequate preparation by the students or insufficient clarity on the part of the instructor, such as in his/her presentations, assignments, and material. Finally, the information that traditional examinations provide is often not timely because the exams are retrospective, shedding light on work and material in weeks past rather than in the present. The most effective assessment centers on levels of student learning. To the extent that assessment is routine and continuous throughout a course (not simply at the end of the term), it will prove most useful to solving students’ leaning difficulties or problems. Immediately knowing that problems exist in a course enables the instructor to respond to difficulties “as they arise”. However, this approach to assessment implies high levels of student participation in the course. For example, students must routinely comment on or evaluate presentations, assist in the development and analysis of examinations and assignments, or participate collaboratively with the instructors and teaching assistants in the teaching and learning material. The course becomes somewhat versatile, always changing in character and form in response to problems and issues in student learning that arise over the course of the term. The difficulty, of course, is that large classes, heavy student participation can be enormously burdensome for the instructor, given the obvious logistical challenges.

Role of Class Size in Effective Teaching and Learning Using Student-Centered Pedagogy

One of the main criticisms of large classes is that student learning is passive and shallow. Faculty lecture and students take notes without much interaction or exchange; material is learned for exams and then quickly forgotten at the end of the term. Because deep learning is more likely to occur when students repeatedly interact with the material and instructor, many faculty members seek strategies for incorporating more active learning into large classes.

Although many researchers have creatively suggested active learning inside the classroom, but as class size increases, most instructors indicate that the level of participation decreases. Too often class size dictates the procedures used to transmit knowledge to students. Recent research and experimentation suggest that active learning can function in both large and small classrooms. A recent collection of articles dedicated to active learning suggests that class size make little difference in the success or failure of active learning. Small classes are not necessarily needed for meaningful learning experiences.
METHODS

Data Analysis

This preliminary analysis of the study employed a descriptive and correlational research design to investigate the dynamics of course continuity from prerequisites to target courses. Quantitative data collection was employed which allowed the data to be quantified and analyzed. To ensure confidentiality, a dataset was built using student identification numbers, however, as soon as the dataset was completed, all student identifiers were removed prior to any analysis and all results were presented in aggregate form such that no individuals can be identified. This ensured that the investigators in this project cannot identify the individuals to whom the data pertain.

Population

The population of this study was engineering students enrolled at San Jose State University. San Jose State University, located in heart of Silicon Valley, ranked ninth in the Western United States in terms of ethnic diversity among colleges and universities conferring bachelor’s and master’s degrees (San Jose State University website, 2018). The sample population was students enrolled in mechanics of materials (CE 112), dynamics (ME 101), and introduction to circuit (EE 98) courses in spring 2017. Demographic characteristics in this study included a total of 235 students –frequency by gender, major, work commitment is shown in the table below.

The students’ majors include aerospace engineering, civil engineering, mechanical engineering, biomedical engineering, chemical engineering, computer engineering, electrical engineering, and materials engineering. Majors were grouped into two categories: “intensive solid-mechanics based majors” (ISMB majors) and “non-intensive solid-mechanics based majors” (Non-ISMB majors). Aerospace engineering, civil engineering, mechanical engineering majors were categorized as ISMB. Biomedical engineering, chemical engineering, computer engineering, electrical engineering, and materials engineering were categorized as non-ISMB majors.

Table 1 – Frequency by Gender, Major, and Work Commitment

<table>
<thead>
<tr>
<th></th>
<th>Frequency (n)</th>
<th>Percent (%)</th>
</tr>
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<tbody>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>187</td>
<td>80</td>
</tr>
<tr>
<td>Women</td>
<td>44</td>
<td>19</td>
</tr>
<tr>
<td>Prefer Not to Answer</td>
<td>4</td>
<td>1</td>
</tr>
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<table>
<thead>
<tr>
<th><strong>Major</strong></th>
<th>ISMB</th>
<th></th>
<th>NON-ISMB</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace Engineering</td>
<td>8</td>
<td>3</td>
<td>Biomedical Engineering</td>
<td>13</td>
</tr>
<tr>
<td>Civil Engineering</td>
<td>41</td>
<td>17</td>
<td>Chemical Engineering</td>
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<tr>
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<td>97</td>
<td>41</td>
<td>Computer Engineering</td>
<td>37</td>
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<tr>
<td>Electrical Engineering</td>
<td>23</td>
<td>16</td>
<td>Electrical Engineering</td>
<td>23</td>
</tr>
<tr>
<td>Materials Engineering</td>
<td>7</td>
<td>3</td>
<td>Materials Engineering</td>
<td>7</td>
</tr>
<tr>
<td><strong>UNDECLARED</strong></td>
<td>7</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| **Work Commitment** | Working | 128 | 54 |


Procedure, Measures, and Results

Data were obtained in the spring of 2017 via surveys administered at the end of the semester in 3 fundamental engineering courses: mechanics of materials, dynamics, and introduction to circuit. In the semester the surveys were administered, 172 students were enrolled in mechanics of materials, 183 students were enrolled in dynamics, and 236 were enrolled in introduction to circuit. Each course was divided into 3 smaller sections for lecture – thus enrollment in each section is around 60–80 students, which still fits the category of large class size. Out of this population of students, 54 students (31%) in mechanics of materials, 68 students (37%) in dynamics, and 113 students (48%) in introduction to circuit responded to our surveys.

Research Question 1: Do gender, major, and work commitment contribute to failure rate in mechanics of materials, dynamics, and introduction to circuit in SJSU? Due to violations of normality when examining the histogram of the dependent variable, the results were validated using a nonparametric independent samples test, as shown in Figures 1-3. The Mann-Whitney U-test was used to assess for significant differences. It is the non-parametric equivalent of the independent samples t-test. Because the test does not assume any properties regarding the distribution of the dependent variable in the analysis, the Mann-Whitney U-test was the appropriate analysis to use when analyzing dependent variables in this study. Results show that indeed there is no statistically significant difference in gender, major, and work commitment as measured through final course grade in all 3 courses –thus the second research question, comparisons of learning dynamics of a classroom (large versus small) were analyzed.

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 The distribution of Final Course Grade is the same across categories of Gender.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.173</td>
<td>Accept the null hypothesis.</td>
</tr>
<tr>
<td>2 The distribution of Final Course Grade is the same across categories of Major.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.161</td>
<td>Accept the null hypothesis.</td>
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<tr>
<td>3 The distribution of Final Course Grade is the same across categories of Work Commitment.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.063</td>
<td>Accept the null hypothesis.</td>
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</tbody>
</table>

Asymptotic significances are displayed. The significance level is 0.05.

Figure 1. Results of nonparametric independent samples tests of Mechanics of Materials.
Figure 2. Results of nonparametric independent samples tests of Dynamics.

<table>
<thead>
<tr>
<th>Null Hypothesis</th>
<th>Test</th>
<th>Sig.</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The distribution of Final Course Grade is the same across categories of Gender.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.064</td>
<td>Accept the null hypothesis.</td>
</tr>
<tr>
<td>2. The distribution of Final Course Grade is the same across categories of Major.</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.141</td>
<td>Accept the null hypothesis.</td>
</tr>
<tr>
<td>3. The distribution of Final Course Grade is the same across categories of Work Commitment</td>
<td>Independent-Samples Mann-Whitney U Test</td>
<td>0.073</td>
<td>Accept the null hypothesis.</td>
</tr>
</tbody>
</table>

Figure 3. Results of nonparametric independent samples tests of Introduction to Circuit.

Research Question 2: Does taking prerequisite courses at community college versus SJSU influence the outcome of the target courses?

In SJSU, as in most engineering colleges, math and physics prerequisites play a major role in students’ success. Figure 4 below summarizes this conclusion. Each of the 3 courses studied has either a math or physics prerequisite. The prerequisites for mechanics of materials, dynamics, and introduction to circuit are ordinary differential equation, calculus II, and general physics of electricity and magnetism, respectively. Students are free to take these prerequisites in either a community college or SJSU. Grades of A+, A, and A- earned are pooled into one group called the “As”. The “Bs” and the “Cs” are grouped in a similar fashion, accordingly. Our analysis revealed that grades in math or physics prerequisites taken at SJSU has low bearing in students’ success –14%, 27%, and 36% of the Bs students taking the math or physics prerequisite course at SJSU failed mechanics of materials, dynamics, and introduction to circuit, respectively and 28%, 25%, and 52% of the Cs students taking the math or physics prerequisite course at SJSU failed mechanics of materials, dynamics, and introduction to circuit, respectively. Compare this with 13%, 14%, and 15% of the Bs students taking the math or physics prerequisite course at a community college failed mechanics of materials, dynamics, and introduction to circuit and 33%, 28%, and 36% of the Cs students taking the math or physics prerequisite course at community colleges failed mechanics of materials, dynamics, and introduction to circuit, respectively. The comparison is between taking prerequisite courses within the university or in a community college. All the mechanics of materials, dynamics, and introduction to circuit courses were taken in the college of engineering at SJSU. In general, the number comparisons between taking the prerequisite courses in community college or within the university do not seem to be striking for mechanics of materials and dynamics –however, it is for introduction to circuit. The results showed that 36% of students who took the physics prerequisite (electricity and magnetism) at SJSU for introduction to circuit and received a B grade (B+, B, B-) failed the course –compare this with 15% of students who took the physics prerequisite at a community college. It also showed that 52% of students who took the physics prerequisite at SJSU for introduction to circuit and received a C grade (C+, C, C-) failed the course –compare this with 36% of students who took the physics prerequisite at a community college. Grade of a B or a C are passing grades –however with as many as 1/3 to ½ taking the physics prerequisite at SJSU failed the introduction to circuit course is quite astonishing. Might it be the comparison between taking the physics prerequisite within the university and community college be classrooms is size and the
complexity that comes with it? Might it be that failure rate in engineering be decreased for some introductory engineering courses with a simple move to smaller class size? The urgency for a new paradigm in teaching fundamental engineering courses in the college of engineering at SJSU is SJSU is imminent. In this preliminary analysis the prerequisite course to introduction to circuit analyzed was general physics of electricity and magnetism, which has strong and direct relationship to the course. The prerequisites course to mechanics of materials and dynamics analyzed were differential equation and calculus II, respectively – these do not have as strong and direct relationship to the target courses. Thus, more analysis will be performed as to understand the complex failure rates in mechanics of materials and dynamics in the second paper of this study.

Table 2 – Percentages Comparison of Failure Rates

<table>
<thead>
<tr>
<th>Course</th>
<th>SJSU (%)</th>
<th>Community College (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanics of Materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As (grades of A+, A, A-)</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>Bs (grades of B+, B, B-)</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Cs (grades of C+, C, C-)</td>
<td>28</td>
<td>33</td>
</tr>
<tr>
<td>Dynamics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As (grades of A+, A, A-)</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Bs (grades of B+, B, B-)</td>
<td>27</td>
<td>14</td>
</tr>
<tr>
<td>Cs (grades of C+, C, C-)</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Introduction to Circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>As (grades of A+, A, A-)</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Bs (grades of B+, B, B-)</td>
<td>36</td>
<td>15</td>
</tr>
<tr>
<td>Cs (grades of C+, C, C-)</td>
<td>52</td>
<td>36</td>
</tr>
</tbody>
</table>

RECOMMENDATION

A new paradigm is needed to cater to the very complex dynamics of student learning in commuter schools, such as SJSU. These students are juggling classes and a job or family or both. Most of our education system is not built to cater to their needs, and its results are extremely wasteful –30% failure rate year in and year out in fundamental engineering courses cannot simply be tolerated as an unfortunate reality. Active learning should no longer be an option –it must be treated as the key ingredient in attempting to start solving this failure catastrophe. The frame of active learning should contain many interactive elements, including weekly lectures, in-class activities, online activities, and hands-on lab exercises –all done during the 75-minute class time in each lecture, thus not changing any curriculum structure. Each element of the new paradigm is described below –mechanics of materials topics shall be used as examples. The author teaches mechanics of materials and have designed a new paradigm in teaching these courses –thus for the purpose of convincing the reader of what this new paradigm entails, examples below are that of mechanics of materials. This paradigm was created during her postdoctoral studies at Stanford University under the guidance of Professors Sheri Sheppard and Sarah Billington. However, these elements may easily be adopted for dynamics and introduction to circuit –which will be published in the second paper of this study by the author.
**Lecture**

Class will still be held two times per week for 110 minutes each period—thus changing nothing to credit unit hours. Lectures, in general, should cover about 20 minutes of class and must be planned with a minimalistic approach, focusing on the essential points. The remainder of class period will be designed for in-class activities, including problem-solving as well as hands-on lab experiments.

**In-Class Activity**

In-class activities shall be based on active-learning strategy, in which students work on a problem posed by the instructor—at times individually and other times in pairs or in groups, before participating in a class-wide discussion. The motivation of these activities is not only to allow students to express their reasoning, reflect on their thinking, and obtain feedback on their understanding; but to also “catch” unengaged and uncovered preconceptions.

**Hands-On/Lab Activity**

Hands-on lab activities for class shall be designed based on research using the approach of scenario-based learning pedagogy. Scenario-based learning involves real world hands-on experience where students were given a scenario problem to solve. Each hands-on activity will take about 40-50 minutes of class time. Several examples of in-class activities are shown in Figure 5 below.

**Online Activity**

Several times during the course, online activities should be assigned to students. The activities shall be embedded as part of homework. Each online activity shall take approximately 35-45 minutes to complete and students shall complete them outside of class at their own convenience. Questions in the online activities will be created using a surveying tool, Qualtrics, and designed to be interactive. The questions placed strong emphasis on applying fundamental understanding of solid mechanics, such as drawing free-body diagrams and drawing shear force and bending moment diagrams to real world examples and scenarios, rather than memorizing definitions and facts. Qualtrics allows for automatic assignment grading, student progress tracking, and performance analytics, all of which will be linked to the class learning management system.

Each question shall be designed to provide interactive feedback to increase student learning and retention. Short videos will be placed strategically throughout the online activities to aid and remind students of fundamental concepts learned during class. The online activities are meant to provide active-learning interventions in which students practiced problem-solving with hints and
feedback for increasing student understanding of fundamental concepts of introductory solid mechanics. Example questions of online activities are shown in Figure 6.

“What kind of force is the weight of the longboard?”

“How should the fixed support at E be drawn?”

“Cut anywhere between segment A and B, what kind of function would the shear force diagram be?”

Figure 6. Online Activity Examples

A pilot course, which will include the aforementioned elements, in mechanics of materials in the college of engineering at SJSU will be offered in Spring 2019. The author of this paper will teach the course. Her hypothesis is that the students participating in this course redesign, particularly in the longitudinal study in mechanics of materials, dynamics (after the pilot course has been offered), and introduction to circuit (after the pilot course has been offered) will remain in engineering through graduation to a greater extent, earn higher grade point averages in engineering, and develop more positive attitudes about engineering and about their own capabilities than do students who go through the traditionally taught curriculum.
LIMITATIONS OF STUDY

The principal objective of this phase of the study was to investigate student backgrounds, classroom dynamics, and prerequisite courses taken. There may be a limited generalizability and a potential for bias from the future findings due to the absence of a randomization of the selected sample participants, due to the fact that: class sections were selected by individual students and/or their academic advisors. Also, class size is certainly one difference between community colleges and SJSU, however, there are a number of other differences between these populations that might also help explain the observed difference in academic performance, such as socioeconomic status, parents’ education, and ethnicity. Thus, caution should be exercised when generalizing the findings of this study to other populations.

DEFINITIONS OF TERMS

1. *Large classes* refers to classes of more than forty students\(^\text{15}\).  
2. *Passive learning* refers to the typical lecture format where the instructor speaks at the front of the room and the class sits facing the instructor. Interaction between the teacher and students often appeared stiff and limited to questions and answers. The typical lecture format limited interaction among students during class time.  
3. *Active learning* refers to something “other than” the traditional lecture format. The concept of active learning is simple: rather than the teacher presenting facts to the students, the students play an active role in learning by exploring issues and ideas under the guidance of the instructor. Instead of memorizing, and being mesmerized by a set of often loosely connected facts, the student learned a way of thinking, asking questions, searching for answers, and interpreting observations.

This is an ongoing study for the college of engineering at SJSU. This paper serves as a preliminary analysis to it. The author hopes to publish the second part of this paper in ASEE next year. Future work might be to test on the hypothesis that the distribution of final course grades is (or is not) the same no matter where the relevant prerequisites were taken.
References


