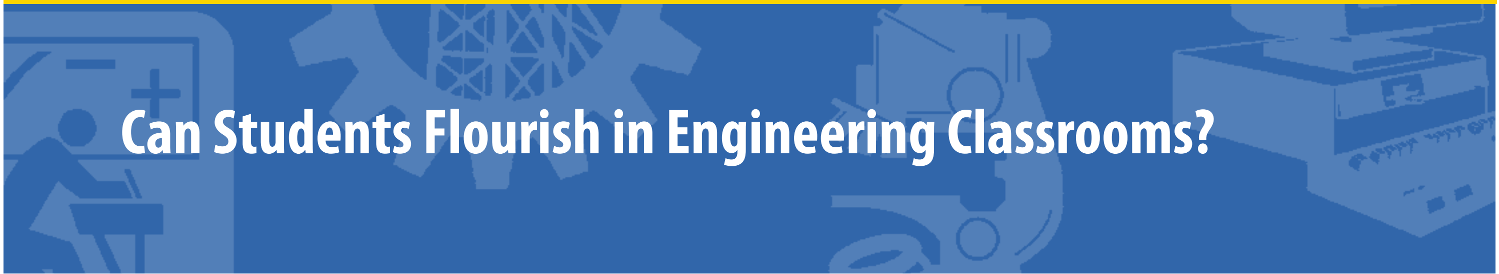

Can Students Flourish in Engineering Classrooms?

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Abstract

This study investigated the role of a new paradigm in teaching large introductory, fundamental engineering mechanics (IFEM) courses that combined student-centered learning pedagogies and supplemental learning resources. Demographic characteristics in this study included a total of 405 students, of whom 347 (85.7%) are males and 58 are (14.3%) females. The students' majors included aerospace engineering, agricultural engineering, civil engineering, construction engineering, industrial engineering, materials engineering, and mechanical engineering.

Results of this study, as tested using an independent samples *t*-test, validated using a nonparametric independent samples test, and a general linear multivariate model analysis, indicated overwhelmingly that there is a difference between a class taught passively using the teacher-centered pedagogy and a class taught actively using student-centered pedagogy.

The principal focus of this work was to determine if the new paradigm was successful in improving student understanding of the course concepts in statics of engineering using student-centered pedagogies in large classes. After evaluating the effects of several variables on students' academic success, the results may provide important information for both faculty members and researchers and present a convincing argument to faculty members interested in academic reform but hesitant to abandon conventional teaching practices. By promoting a new paradigm, the potential for improving understanding of engineering fundamentals on a larger scale may be realized.

Introduction

IFEM courses, which include statics of engineering, mechanics of materials, dynamics, and mechanics of fluids are essential components to many engineering disciplines (Steif & Dollar, 2008). This study is an evaluation of a new paradigm incorporating a pedagogical reform that was performed over two semesters at Iowa State University (ISU) in its College of Engineering. The focus of the new paradigm was to use student-centered learning to promote better understanding of conceptual fundamental knowledge for students.

Student-centered learning was first introduced as early as the 1960s under a reform pedagogy called guided inquiry (Karplus & Their, 1969). It was introduced in 3 phases: an exploration phase, an invention phase, and an application phase. This pedagogy has been found to provide students with a significantly better conceptual understanding compared to students taught traditionally (Barman, Barman, & Miller, 1996; Marek, Cowan, & Cavallo, 1994; Stephans, Dyche, & Beiswenger, 1988).

Traditionally taught students are understood as those whose instruction primarily focuses on verbal and printed words, rote memorization, and is instruction driven (Schneider & Renner, 1980). Students who are taught traditionally are told what they are expected to know and concepts are presented deductively, where the faculty conducts lessons by introducing and explaining concepts to students, and then expecting students to complete tasks to practice the concepts. Modern interpretations of student-centered learning include project-based learning, case-based learning, discovery learning, and just-in-time teaching with 3 instructional approaches of active learning, cooperative learning, and problem-based learning (Prince & Felder, 2004).

With the hope of effectively investigating the most fruitful way to teach IFEM courses in large lectures, and to compare the *traditional pedagogy*, which is the full 50-minute lecture, three times a week class to an *experimental pedagogy,* which is the 50-minute, three times a week class centered on active learning, this quantitative study was designed to explore variables affecting student academic success. The variables included demographic characteristics and grades earned in class, including examinations grades, homework grades, and final class grades. This study was conducted using data from 2 semesters in statics of engineering (EM 274) at ISU from 2 different faculty members teaching 2 different sections, one using the traditional-style pedagogy and the other using an experimental pedagogy.

Statics of engineering was chosen because its concepts and applications are needed in almost every discipline of engineering (Benson et al., 2010; Rutz et al., 2003). It is a fundamental prerequisite for subsequent courses such as mechanics of materials, dynamics, and mechanics of fluids, and in some programs, other courses such as tool design, etc. (Beer & Johnston, 2004; Orr, Benson, & Biggers, 2008). Many researchers (Beer & Johnston, 2004; Orr et al., 2008; Rutz et al., 2003) believe that performance in these later courses can be directly correlated to success in statics of engineering.

In the past, statics of engineering has often been taught in a traditional lecture and note-taking approach. According to current understanding (Thomas, Subramaniam, Abraham, Too, & Beh, 2011; Zorn & Kumler, 2003), humans think, learn, and solve problems by making connections and associations to previous experiences. Numerous researchers (Gleason, 1986; Thomas et al., 2011; Zorn & Kumler, 2003) have written that if one's first exposure to fundamental concepts takes place by passively hearing it in lecture or by reading it in a textbook, the experience may not be sufficiently significant or rich to build connections. Thus, determining factors that could facilitate academic success in statics of engineering should be a major concern in engineering education.

Literature Review

Introduction of Literature

As seen from decades of scholarly work about student-centered learning in engineering, there seems to be some validity to the claim that engineering colleges are "slow to change" (Basken, 2009). Also, it appears to be unproductive to expect education change to occur immediately at any macro-level, either governmental or institutional. This leads to the conclusion that expectations for educational change should focus on change at the micro-level within specific settings where teaching and learning is occurring—the classroom. Now the questions become, what type of micro-level changes should occur, particularly in IFEM courses, such as statics of engineering, mechanics of materials, dynamics, and mechanics of fluids; and what should be the goals of this change?

A review of the literature supports the idea that the climate of the education setting in teaching IFEM courses should change from instructor-controlled, passive learning to an environment that encourages mutually controlled, active learning (Abdulaal, Al-Bahi, Soliman, &Iskanderani, 2011; Hsieh & Knight, 2008; Kotru, Burkett, & Jackson, 2010; Myllymaki, 2012). Also supported in the literature is the statement that the goal of teaching any introductory, fundamental courses of any discipline should be to improve learners' fundamental concepts of the respective discipline and their critical thinking skills (Ahern, 2010; Pierce, 2013). Scholars active in this field (Abdulaal et al., 2011; Vallim, Farines, & Cury, 2006) believe that active learning cannot and should not be taken out of the process of teaching. For the purpose of this article, the authors define active learning as a classroom ethos in which students are responsible not only for their own learning but also for that of their peers.

Most would agree that from a practical perspective, everyday life involves being able to function successfully, actively, and cooperatively in groups, not only in the work place, but also within the family unit. This concept also gives an important educational justification as studied by Magno (2010), which showed that successful actively and cooperatively engaged thinkers have strong metacognitive abilities—they know what they know and do not know, can plan a strategy, are conscious of the steps taken, and can reflect on and evaluate their thinking.

In general, student learning can be broadly categorized into two groups of pedagogies—the traditional *teacher-centered pedagogy* and the *student-centered pedagogy* (Huba & Freed, 2000). According to Huba and Freed (2000), the teacher-centered pedagogy involves knowledge transmission from faculty to students, who passively receive information. They assert that in a teacher-centered environment assessments are used to monitor learning with an emphasis on the right answer and the learning culture is competitive and individualistic. These features are contrasted by the student-centered pedagogy that actively involves students in constructing knowledge. Many researchers (Abdulaal et al., 2011; Hsieh & Knight, 2008; Kotru et al., 2010; Myllymaki, 2012) agree with Huba and Freed (2000) that the student-centered method emphasizes generation of better questions, learning from errors, and assessments that are used to diagnose and promote learning. All of these researchers above argue that the learning culture should be active, cooperative, collaborative and supportive, wherein both the faculty members and students learn.

Active Learning

Proponents of teacher-centered pedagogy (Detlor, Booker, Serenko, & Julien, 2012; Drew & Mackie, 2011; Kim, Sharma, Land, & Furlong, 2013; Leng, Xu, & Qi, 2013; Rahmat & Aziz, 2012; Scott, 2011; Stephen, Ellis, & Martlew, 2010) argue that the usual lecture method as seen in the majority of engineering classrooms (Froyd & Ohland, 2005; Turns, Atman, Adams, & Barker, 2005; McClain & DeLoatch, 2005; Dym, Agogino, Eris, Frey, & Leifer, 2005) would be more effective when used along with other teaching strategies. Students will remember more if brief activities are introduced to the lecture and they are "actively" performing something other than just listening (Prince & Felder, 2004). Several researchers (Hsieh & Knight, 2008; Laws, Sokoloff, & Thornton, 1999), who incorporated active learning strategies in their instruction, have shown significant positive effects on student learning and perception. These researchers argue that the term "active learning", as the term suggests, should be defined as an instruction method or a learning experience, which is "active" in nature. Either physical or cognitive action can keep students and faculty engaged with both becoming active participants in the learning process. The term "participants" is very crucial in describing active learning because both the students and the instructor "participate", hence learning from the experience (Rahmat & Aziz, 2012). Both are "active" and the explicit intent of active learning methods is not only to improve the learning of students, but also the development of the faculty member as he/she refines his/her strategies in the teaching-learning process. A working definition for active learning in a college classroom is proposed as a learning method that "involves students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991).

Bonwell and Eison (1991) listed some general characteristics associated with active learning strategies in a classroom: students are involved in more than listening; less emphasis is placed on transmitting information and more on developing students' skills; students are involved in higher-order thinking (e.g., analysis, synthesis, evaluation); students are engaged in activities (e.g., reading, discussing, writing, etc.); and greater emphasis is placed on students' exploration of their own attitudes and values.

Carmean and Haefner (2002) developed a core set of *Deeper Learning Principles*, which is an engaged learning that results in a meaningful understanding of material and content. The Deeper Learning Principles include learning that is social, active, contextual, engaging and student-owned. Along with these principles there is also a need to emphasize the importance of long-term memory and learning based on building enduring conceptual structures (Detlor et al., 2012; Drew & Mackie, 2011; Foreman, 2003; Kim et al., 2013; Leng et al., 2013; Rahmat & Aziz, 2012; Scott, 2011; Stephen et al., 2010).

The one underlying emphasis that can sum up these views on active learning is that the real understanding of concepts can be revealed in the ability of the learner to apply the concepts that they have learned in different situations (Rahmat & Aziz, 2012). Not just factual information recall, but a more applied use of the gained factual knowledge, can be credited to an effective learning experience.

Issues of Active Learning

In the review of emerging issues in student-centered pedagogies some researchers (e.g., Bonwell & Eison, 1991) have listed several reasons for the hesitation in adopting active learning techniques in college classrooms, such as faculty evaluation by students and the administration, classroom environments, assessments in both institutional and class level, and the need for more supporting resources. Bonwell and Eison (1991) highlighted 5 important barriers in adopting active learning strategies, which include inability to cover content, time required to prepare for classes, inability to use it in large classes, lack of materials and resources, and the risk of evaluation by students and peer instructors.

Since transfer of information in a one-way path from faculty member to student is less time consuming compared to a two-way or rather multi-way path of discussions and questions, a common criticism of the student-centered instructional model, as indicated by Bonwell and Eison (1991), is its inherent tendency to take more time than a traditional lecture model to cover the same content. The need to spend more time in preparing and delivering an active learning method of instruction can inhibit faculty from trying and testing its benefits. For a higher-quality faculty professional development, more research needs to be done in this subject of implementing active learning (Slavin, 1991). So, one of the main challenges of this study is to devise an active learning strategy that not only enhances the experience and effectiveness but also remains within the same time period as a regular lecture format—How can active learning concepts be incorporated in IFEM courses, such as statics of engineering, mechanics of materials, dynamics, and mechanics of fluids curriculum to enhance the teaching and learning experience of the faculty and the students without a huge shift from the traditional methods of instruction? This article attempts to answer that question.

Active Learning in Large Lectures and the Role of Class Size

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:

1. Careful design and preparation of the course (Zorn & Kumler, 2003)
2. The quality of the instructor's presentations to students (Al Nashash, 2013)
3. The level of administration and management of the course (Cakmak, 2009)
4. Implementing some form of active or experiential learning, which will engage students more effectively (Myllymaki, 2012)
5. Use of multimedia (Rowland-Bryant, Skinner, & Dixon, 2011; Walker, Cotner, & Beermann, 2011)
6. Adequate preparation of graduate student teaching assistants to aid in the classroom (Sargent, Allen, &

Frahm, 2009)

7. The level of managing assessments (Wanous, Procter, & Murshid, 2009)

Although many researchers (Al Nashash, 2013; Cakmak, 2009; Fata-Hartley, 2011; Yazedjian & Kolkhorst, 2007) have creatively suggested ways to achieve active learning inside the classroom, but as class size increases most faculty indicate that the level of participation decreases. Too often class size dictates the procedures used to transmit knowledge to students. Recent research and experimentation (Ahern, 2010) suggest that active learning can function in both large and small classrooms. A recent collection of articles dedicated to active learning (Al Nashash, 2013; Cakmak, 2009; Fata-Hartley, 2011; Yazedjian & Kolkhorst, 2007) suggests that class size makes little difference in the success or failure of active learning. Small classes are not necessarily needed for meaningful learning experiences.

Summary of Literature

Research has shown across the board the effects of active learning are positive and robust. When compared to implementation strategies suggested in the literature (Vest, 2008; Bielenberg, 2011; Felder, Brent, Prince, 2011) the active learning model appears to be a strong model for fostering the development of students' understanding of fundamental engineering concepts in large classes, such of statics of engineering, mechanics of materials, dynamics, and mechanics of fluids. If implementing an active learning model does improve the growth of students' engineering fundamental knowledge, the case for active learning in large classes as a way to implement micro-level educational change becomes even stronger in the first and second-year engineering curriculum.

Research Question

This study sought to answer the question, *do active learning pedagogies in large classes improve student ability to understand course concepts and learn problem-solving measured through semester examination scores, homework scores, and final class grades?*

Methodology

Population

The population of this study was engineering students enrolled at ISU. Located in Ames, Iowa, ISU, ranks in the top twenty in engineering bachelor degrees awarded in aerospace, chemical, civil, industrial and manufacturing, mechanical, and computer engineering (ISU website, 2013). The population from which the respondents were drawn are students enrolled in statics of engineering (EM 274) classes in fall 2012 and spring 2013. The sample consisted of a total of 405 students, of whom 347 (85.7%) are males and 58 (14.3%) are females. The students' major include the typical majors required to take statics of engineering in an engineering college: aerospace engineering, 74 students (18.3%); agricultural engineering, 8 students (2.0%); civil engineering, 62 students (15.3%); construction engineering, 14 students (3.5%); industrial engineering, 24 students (5.9%); materials engineering, 33 students (8.1%); and mechanical engineering, 169 students (41.7%). There were 21 students (5.2%) who were from outside the majors mentioned above.

Design and Procedure

This study aimed to answer the overarching question of whether there is a difference in student performance in an IFEM class of statics of engineering between the *traditional*, teacher-centered pedagogy, 50-minute, three times a week class (passive learning) and an *experimental*, student-centered pedagogy, 50-minute, three times a week class, which involved interventions including supplemental videos and interactive-teaching style (active learning). A comparison was designed to focus on three areas of progress, which were student examination scores, student homework scores, and student overall class performance.

Passive learning featured in this study is the typical lecture format where the instructor speaks at the front of the room and the class sits facing the instructor. Interaction between the instructor and students often appear stiff and limited to questions and answers. The typical lecture format limits interaction among students during class time.

Active learning, on the other hand, implied by its very title, is something "other than" the traditional lecture format. The concept of active learning in this study is simple: rather than the instructor 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 students learn a way of thinking, asking questions, searching for answers, and interpreting observations.

In this research, a cross sectional, ex-post facto study was carried out on two groups of participants during two different semesters: 1) undergraduate students at ISU who were enrolled in the *traditional statics of engineering class* during two different semesters, fall 2012 and spring 2013, and 2) undergraduate students at ISU who were enrolled in an *experimental pedagogy statics of engineering class* during the same two semesters, fall 2012 and spring 2013.

Independent Variable

The independent variable used in this study is *type of class*—traditional, passive learning class versus experimental, active learning class. The traditional class was a 50-minute, three times a week class, passive pedagogy, teacher-centered learning approach. The experimental class was a 50-minute, three times a week class, active pedagogy, student-centered learning approach. The experimentally taught class involved interventions including supplemental videos and interactive teaching style, which involved think-pair-share, one-minute muddiest point, and problem solving in groups.

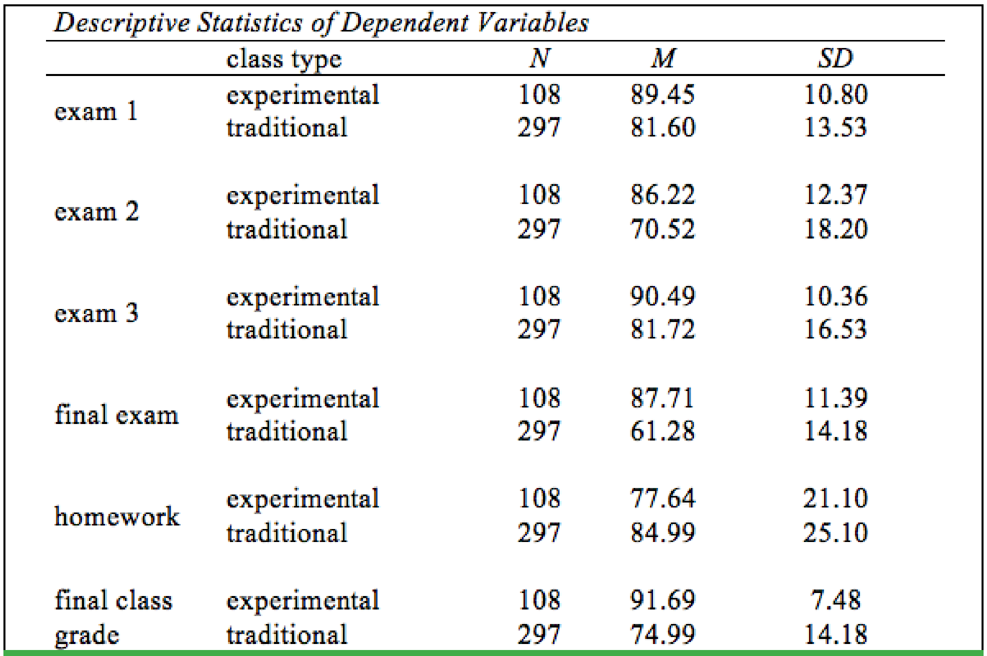
Dependent Variables

The dependent variables used in this study are exam *1 scores, exam 2 scores, exam 3 scores, final exam scores, homework scores, and final class grades.* Exam 1 was an evaluation on topics, which included: introduction to statics, force systems, rectangular versus non-rectangular components, two- and three-dimensional moments, couples, and two- and three-dimensional resultants. Exam 2 was an evaluation on topics, which included: free-body diagrams, two- and three-dimensional equilibrium, frames and machines, trusses, center of mass and centroid, and distributed loads. Exam 3 was an evaluation on topics, which included: beams, friction, second moment of area, product of inertia, and mass moments of inertia. The final exam was an evaluation on the comprehensive topics covered from the beginning of the semester until the end. Three homework problems were assigned for each lecture.

The database of the students' class performance in this study was obtained from individual instructors' databases. One of the authors of this study taught the experimental, student-centered pedagogy, active learning class. Another faculty member taught the traditional, teacher-centered pedagogy, passive learning class. Both instructors used identical methods in calculating students' final class grades, as described in the class syllabus. The class syllabus was distributed to each student on the first day of class and posted on Blackboard Learn throughout the entire semester for student access.

Data Analysis

This study employed an independent samples *t*-test, a nonparametric independent samples test, and a general linear multivariate model analysis to understand the outcome of student learning effectiveness concerning the impact of learning interventions using student-centered pedagogy on their academic learning. With the hope of effectively investigating the most fruitful way to teach IFEM courses in large lectures, this study aimed to answer the overarching question of whether there is a difference in student performance in a large lecture IFEM class of statics of engineering between the traditional 50-minute, three times a week class (passive, teacher-centered learning pedagogy) and an experimental pedagogy, 50-minute, three times a week class, which involved interventions including supplemental videos and interactive-teaching style (active, student-centered learning pedagogy). Quantitative data collection was employed, which allowed the data to be analyzed using statistical analysis procedures provided in SPSS statistical software.



Descriptive Statistics of Dependent Variables

	class type	*N*	*M*	*SD*
exam 1	experimental	108	89.45	10.80
	traditional	297	81.60	13.53
exam 2	experimental	108	86.22	12.37
	traditional	297	70.52	18.20
exam 3	experimental	108	90.49	10.36
	traditional	297	81.72	16.53
final exam	experimental	108	87.71	11.39
	traditional	297	61.28	14.18
homework	experimental	108	77.64	21.10
	traditional	297	84.99	25.10
final class grade	experimental	108	91.69	7.48
	traditional	297	74.99	14.18

Table 1.

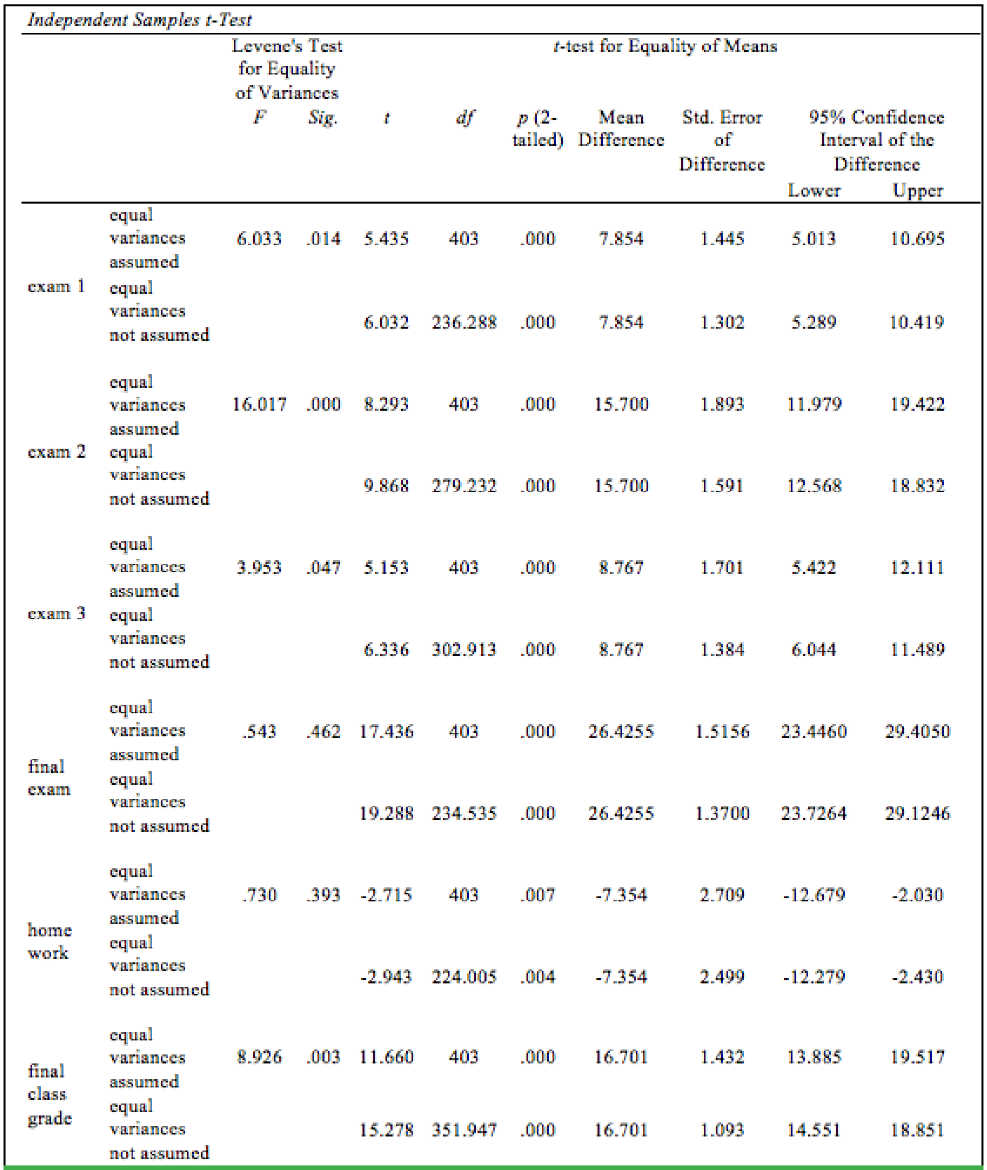
To ensure confidentiality, a dataset was built using student identification numbers; however, as soon as the dataset was completed, all student identifiers were removed prior to any statistical analysis and all results are presented in aggregate form such that no individuals can be identified. This ensured that the investigators of this project cannot identify the individuals to whom the data pertain.

Results and Discussion

Before performing any analysis, histograms of the dependent variables were examined to confirm normality. Normality assumptions were not met; thus the independent samples t-test was validated with a nonparametric independent samples test, and also with a general linear multivariate model analysis. A summary of descriptive statistics (*N*, *M*, and *SD*) of each dependent variable by class type is seen in Table 1. Results, as summarized in Table 1, show that the experimental class (active, student-centered learning pedagogy) has means greater than those of the traditional class (passive, teacher-centered learning pedagogy) in every dependent variable, except for homework grades; and the standard deviations of the experimental class (active, student-centered learning pedagogy) are less than that of the traditional class (passive, teacher-centered learning pedagogy) in every dependent variable.

An independent samples *t*-test was conducted to determine if there were statistically significant differences in student performance, as measured from exam 1 scores, exam 2 scores, exam 3 scores, final exam scores, homework scores, and class grades between students taught using the active, student-centered approach and students taught using the passive, teacher-centered approach. Results, as summarized in Table 2, show that:

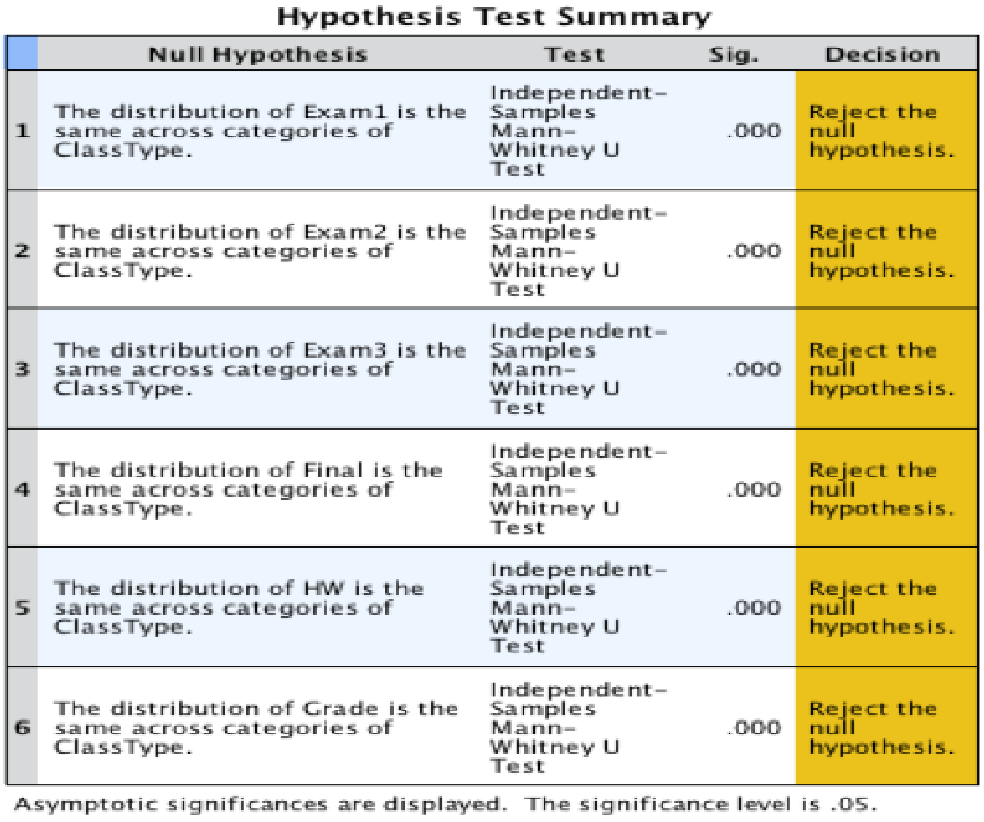
1. There is a *statistically significant difference in the scores of exam 1* for the experimental, active, student-centered class (*M*=89.45, *SD*=10.80) and for the traditional, passive, teacher-centered class (*M*=81.60, *SD*=13.53); *t*(236.288)=6.032, *p* < .001. The effect size for this difference was calculated as 0.6412.
2. There is a *statistically significant difference in the scores of exam 2* for the experimental, active, student-centered class (*M*=86.22, *SD*=12.37) and for the traditional, passive, teacher-centered class (*M*=70.52, *SD*=18.20); *t*(279.232)=9.868, *p* < .001. The effect size for this difference was calculated as 1.0089.
3. There is a *statistically significant difference* in the scores of *exam 3* for the experimental, active, student-centered class (*M*=90.49, *SD*=10.36) and for the traditional, passive, teacher-centered class (*M*=81.72, *SD*=16.53); *t*(302.913)=6.336, *p* <



Independent Samples t-Test

		Levene's Test for Equality of Variances		*t*-test for Equality of Means					95% Confidence Interval of the Difference	
		F	*Sig.*	*t*	*df*	*p* (2-tailed)	Mean Difference	Std. Error of Difference	Lower	Upper
exam 1	equal variances assumed	6.033	.014	5.435	403	.000	7.854	1.445	5.013	10.695
	equal variances not assumed			6.032	236.288	.000	7.854	1.302	5.289	10.419
exam 2	equal variances assumed	16.017	.000	8.293	403	.000	15.700	1.893	11.979	19.422
	equal variances not assumed			9.868	279.232	.000	15.700	1.591	12.568	18.832
exam 3	equal variances assumed	3.953	.047	5.153	403	.000	8.767	1.701	5.422	12.111
	equal variances not assumed			6.336	302.913	.000	8.767	1.384	6.044	11.489
final exam	equal variances assumed	.543	.462	17.436	403	.000	26.4255	1.5156	23.4460	29.4050
	equal variances not assumed			19.288	234.535	.000	26.4255	1.3700	23.7264	29.1246
home work	equal variances assumed	.730	.393	-2.715	403	.007	-7.354	2.709	-12.679	-2.030
	equal variances not assumed			-2.943	224.005	.004	-7.354	2.499	-12.279	-2.430
final class grade	equal variances assumed	8.926	.003	11.660	403	.000	16.701	1.432	13.885	19.517
	equal variances not assumed			15.278	351.947	.000	16.701	1.093	14.551	18.851

Table 2.



Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Exam1 is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
2	The distribution of Exam2 is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
3	The distribution of Exam3 is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
4	The distribution of Final is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
5	The distribution of HW is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.
6	The distribution of Grade is the same across categories of ClassType.	Independent-Samples Mann-Whitney U Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 1. Results of nonparametric independent samples tests of dependent variables from SPSS (Version 21).

.001. The effect size for this difference was calculated as 0.6357.

4. There is a *statistically significant difference* in the scores of *final exam* for the experimental, active, student-centered class (M=87.71, SD=11.39) and for the traditional, passive, teacher-centered class (M=61.28, SD=14.18); $t(403)=17.436$, $p < .001$. The effect size for this difference was calculated as 2.0550.
5. There is a *statistically significant difference* in the scores of *class grade* for the experimental, active, student-centered class (M=91.69, SD=7.481) and for the traditional, passive, teacher-centered class (M=74.99, SD=14.18); $t(351.947)=15.278$, $p < .001$. The effect size for this difference was calculated as 1.4731.

These results suggest that active, student-centered pedagogy does have an effect on student performance.

Next, the independent samples *t*-test was validated using a nonparametric independent samples test, as shown in Figure 1. Again results, as summarized in Figure 1, show that indeed there are overwhelmingly significant differences in student performance as measured through exams scores and final class grades. The reason this study uses a nonparametric independent samples test is because this approach tests hypotheses while not making

Multivariate Tests[a]

	Effect	Value	F	Hypothesis df	Error df	p	Partial Eta Squared	Noncentrality Parameter	Observed Power[d]
gender	Pillai's Trace	.003	.170[b]	6.000	349.000	.985	.003	1.019	.094
	Wilks' Lambda	.997	.170[b]	6.000	349.000	.985	.003	1.019	.094
	Hotelling's Trace	.003	.170[b]	6.000	349.000	.985	.003	1.019	.094
	Roy's Largest Root	.003	.170[b]	6.000	349.000	.985	.003	1.019	.094
major	Pillai's Trace	.167	1.452	42.000	2124.000	.031	.028	60.986	.997
	Wilks' Lambda	.841	1.467	42.000	1640.407	.028	.028	47.955	.980
	Hotelling's Trace	.179	1.477	42.000	2084.000	.025	.029	62.030	.998
	Roy's Largest Root	.091	4.597[c]	7.000	354.000	.000	.083	32.180	.994
class type	Pillai's Trace	.267	21.147[b]	6.000	349.000	.000	.267	126.883	1.000
	Wilks' Lambda	.733	21.147[b]	6.000	349.000	.000	.267	126.883	1.000
	Hotelling's Trace	.364	21.147[b]	6.000	349.000	.000	.267	126.883	1.000
	Roy's Largest Root	.364	21.147[b]	6.000	349.000	.000	.267	126.883	1.000
semester	Pillai's Trace	.086	5.458[b]	6.000	349.000	.000	.086	32.748	.996
	Wilks' Lambda	.914	5.458[b]	6.000	349.000	.000	.086	32.748	.996
	Hotelling's Trace	.094	5.458[b]	6.000	349.000	.000	.086	32.748	.996
	Roy's Largest Root	.094	5.458[b]	6.000	349.000	.000	.086	32.748	.996

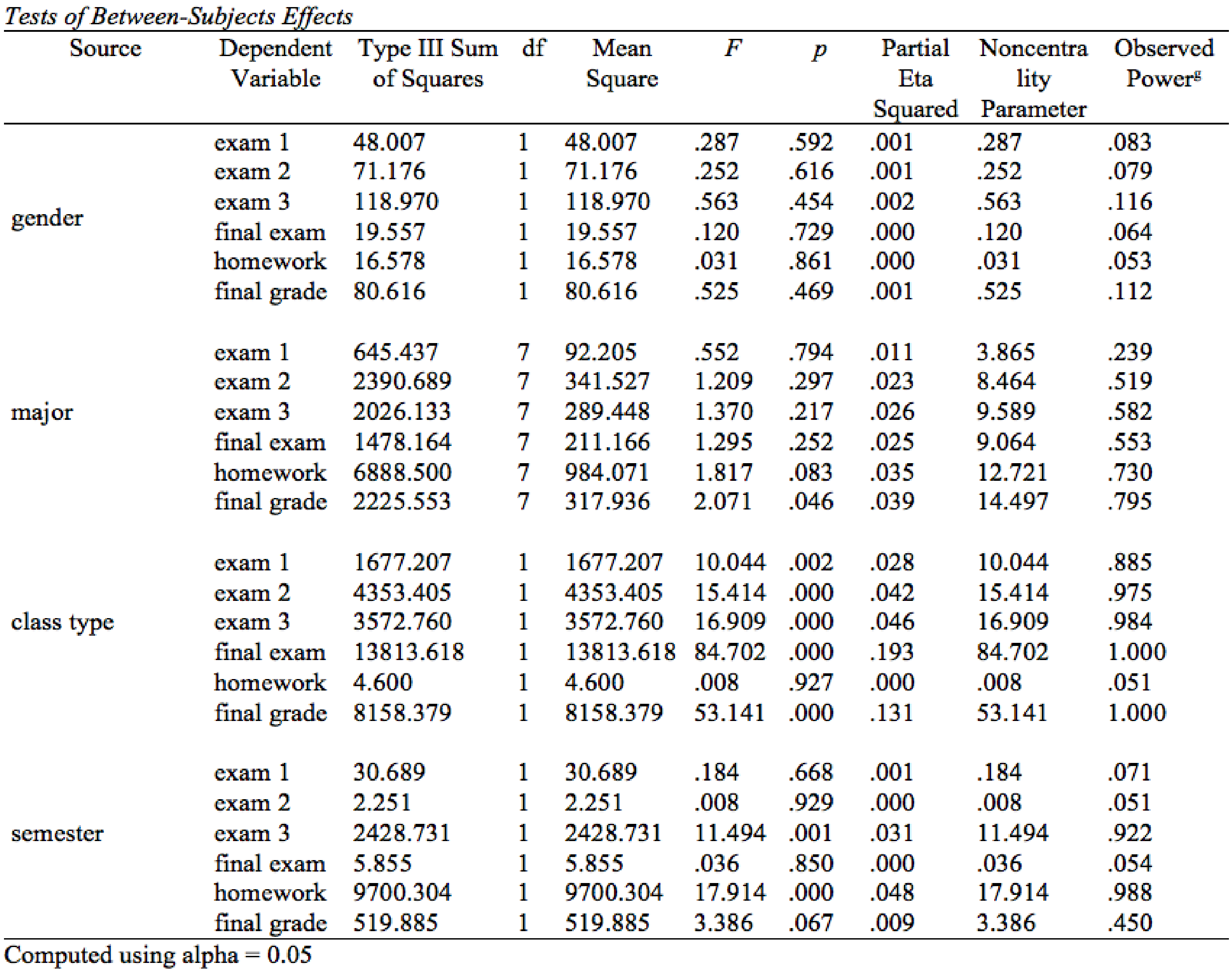
a. Design: gender + major + class type + semester

b. Exact statistic

c. The statistic is an upper bound on F that yields a lower bound on the significance level.

d. Computed using alpha = 0.05

Table 3.



Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	*F*	*p*	Partial Eta Squared	Noncentrality Parameter	Observed Power^g
gender	exam 1	48.007	1	48.007	.287	.592	.001	.287	.083
	exam 2	71.176	1	71.176	.252	.616	.001	.252	.079
	exam 3	118.970	1	118.970	.563	.454	.002	.563	.116
	final exam	19.557	1	19.557	.120	.729	.000	.120	.064
	homework	16.578	1	16.578	.031	.861	.000	.031	.053
	final grade	80.616	1	80.616	.525	.469	.001	.525	.112
major	exam 1	645.437	7	92.205	.552	.794	.011	3.865	.239
	exam 2	2390.689	7	341.527	1.209	.297	.023	8.464	.519
	exam 3	2026.133	7	289.448	1.370	.217	.026	9.589	.582
	final exam	1478.164	7	211.166	1.295	.252	.025	9.064	.553
	homework	6888.500	7	984.071	1.817	.083	.035	12.721	.730
	final grade	2225.553	7	317.936	2.071	.046	.039	14.497	.795
class type	exam 1	1677.207	1	1677.207	10.044	.002	.028	10.044	.885
	exam 2	4353.405	1	4353.405	15.414	.000	.042	15.414	.975
	exam 3	3572.760	1	3572.760	16.909	.000	.046	16.909	.984
	final exam	13813.618	1	13813.618	84.702	.000	.193	84.702	1.000
	homework	4.600	1	4.600	.008	.927	.000	.008	.051
	final grade	8158.379	1	8158.379	53.141	.000	.131	53.141	1.000
semester	exam 1	30.689	1	30.689	.184	.668	.001	.184	.071
	exam 2	2.251	1	2.251	.008	.929	.000	.008	.051
	exam 3	2428.731	1	2428.731	11.494	.001	.031	11.494	.922
	final exam	5.855	1	5.855	.036	.850	.000	.036	.054
	homework	9700.304	1	9700.304	17.914	.000	.048	17.914	.988
	final grade	519.885	1	519.885	3.386	.067	.009	3.386	.450

Computed using alpha = 0.05

Table 4.

assumptions about the population parameters. This approach has the advantage that it applies to a more general condition than do parametric tests (such as the independent samples *t*-test explained earlier). Observation of histograms of the dependent variables clearly shows the absence of a normal distribution, a nonparametric test was justified. The Mann-Whitney test was chosen in SPSS (Version 21) while performing the nonparametric independent samples test.

The result demonstrated in Figure 1 suggests that it is appropriate to reject the null hypothesis that the distribution of grades is the same across categories being analyzed ($p < 0.05$).

Furthermore, a general linear multivariate model analysis was conducted; again, it validated and confirmed the results of the independent samples *t*-test and the nonparametric independent samples tests that indeed there are overwhelmingly significant differences in student performance as measured through exams scores and final class grades as summarized in the results of Tables 3 and 4, particularly on the type of class (traditional—passive, teacher-centered learning pedagogy versus experimental—active, student-centered learning pedagogy).

The results of the general linear multivariate model analysis, as summarized in Table 3, show that the *p*-values of major, class type, and semester reveal that these variables may be used as statistically significant predictors of class performance across exam grades and class grades in statics of engineering as tested using four different effects, Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root.

Examining the *p*-values of *class type* for *exam scores* and *class grade* in Table 4 reconfirms the critical results of the independent samples *t*-test and the nonparametric independent samples test that there is a statistically significant difference between the experimentally-taught students (active learning) and the traditionally-taught students (passive learning) in statics of engineering.

Limitations of the Study

The results of this study were as expected and were supported by the literature regarding active learning for the development of curriculum in engineering education. However, the study was not without limitations:

1. Creating an active, student-centered class is not an easy task for an educator. It takes formal training, experience, and a commitment in terms of willingness to make a change in personal perspective, and in terms of time and effort. A novice attempt at creating such an environment could very well not meet standards of treatment fidelity.
2. The sample was not a cross-sectional sample representative of the college population. The gender ratio strongly favored males, with 347 (85.7%) males and 58 (14.3%) females. Although the gender ratio is considerably less female than the campus as a whole (44%) and less than the majority female population of academia generally, the sample gender distribution more closely reflects the representation of female students within engineering majors.
3. The enrollment ratio strongly favored the traditional-style lecture, with 297 (73.3%) students

enrolled in the traditional-style lecture and 108 (26.7%) students were enrolled in the experimental-style lecture.

4. The enrollment ratio also strongly favored the fall semester lecture, with 257 (63.5%) students enrolled in the fall semester lecture and 148 (36.5%) students were enrolled in the spring semester lecture.
3. Participants were all learning from a single content domain—statics of engineering.
4. The principal objective of this study was to investigate and evaluate outcomes of the experimental pedagogy class in terms of student understanding and data collected from fall 2012 and spring 2013. Any known difference between fall and spring semesters' cohorts may be a limitation to this study, but was not considered as a potential confounding variable.
5. There may be limited generalizability and a potential for bias from the findings of this study due to the absence of randomization of the selected sample participants. This is due to the facts that: 1) class sections were selected by individual students and/or their academic advisors and 2) selection of the experimental pedagogy class was that of the researcher in accordance with teaching assignments assigned by college administrators.

Due to the limitations of this study, caution should be exercised when generalizing the findings of this study to other populations.

Conclusions

This study was begun in hopes of being able to answer the research question of whether there is a difference in student performance in an IFEM class of statics of engineering between the *traditional*, 50-minute, three times a week, teacher-centered pedagogy class (passive learning) and an *experimental*, 50-minute, three times a week, student-centered pedagogy class that involved interventions including supplemental videos and interactive-teaching style (active learning). The results, as tested using an independent samples t-test and validated using a nonparametric independent samples test and a general linear multivariate model analysis, overwhelmingly showed that the students in the class taught actively using the student-centered pedagogy significantly outperformed the students in the class taught passively using the teacher-centered pedagogy, as summarized below:

1. The type of class (traditional or experimental), the time of year (fall or spring), and major, do predict student performance across exam grades and class grades in statics of engineering.
2. Gender (male or female) does not predict student performance across exam grades and class grades in statics of engineering.
3. There is a statistically significant difference between the experimentally-taught students (active learning) and the traditionally-taught students (passive learning) in student performance on exam scores and class grades results in statics of engineering.

Recommendations to Faculty and Future Researchers

Thus, the authors' recommendation is that large IFEM classes, such as statics of engineering, mechanics of materials, dynamics, and mechanics of fluids do not have to be engineering's behemoth. Any faculty member having the privilege of teaching them can restructure the course following student-centered pedagogies and simultaneously benefit by the chance to experience a renewed craft of teaching. The following recommendations are based on the conclusions of this study:

1. Engineering faculty should be encouraged to use student-centered learning pedagogies in their classroom instruction, particularly in IFEM classes.
2. Resources and support within engineering departments should be made available for engineering faculty to learn how to implement student-centered pedagogies in their classrooms.
3. Further study is needed to determine which student-centered strategies engineering professors are most comfortable with and use most effectively.
4. Further study is needed to determine which student-centered strategies have the greatest impact on student learning.
5. Further study is needed to determine which training techniques are most effective in working with engineering faculty to increase their use of student-centered strategies.
6. Further study is needed to determine the effects of student-centered learning in dynamics and mechanics of fluids.
7. Further study is needed to determine the effects of student-centered learning in upper-level major classes.
8. Further study is needed to explore the correlation of student-centered learning in introductory, fundamental classes, such as statics of engineering, mechanics of materials, dynamics, and mechanics of fluids with critical thinking in upper-level major classes.

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References

Abdulaal, R. M., Al-Bahi, A. M., Soliman, A. Y., & Iskanderani, F. I. (2011). Design and implementation of a project-based active/cooperative engineering design course for freshmen. *European Journal of Engineering Education, 36*(4), 391-402.

Ahern, A. A. (2010). A case study: Problem-based learning for civil engineering students in transportation courses. *European Journal of Engineering Education, 35*(1), 109-116.

Al Nashash, H. & Gunn, C. (2013). Lecture capture in engineering classes: Bridging gaps and enhancing learning. *Journal of Educational Technology & Society, 16*(1), 69-78.

Barman, C. R., Barman, N. S., & Miller. J. A. (1996). Two teaching methods and students' understanding of sound. *School Science and Mathematics, 96*, 63-67.

Basken, P. (2009). Retrieved from http://www.ahetems.org/media/docs/gradarticle2091.pdf.

Beer, F. P. & Johnston, E. R. (2004). *Vector mechanics for engineers: Statics and dynamics*. New York: McGraw Hill.

Benson, L. C., Orr, M. K., Biggers, S. B., Moss, W. F., Ohland, M. W., & Schiff, S. D. (2010). Student-centered active, cooperative learning in engineering. *International Journal of Engineering Education, 26*(5), 1097-1110.

Bielenberg, B. (2011). Academic Literacy and Engineering Education: Development Through Cornerstone Design. *Proceeding in American Society for Engineering Education Annual Conference.*

Bonwell, C.C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom* (ASHE-ERIC Higher Education Report No. 1). Washington, D.C.: The George Washington University, School of Education and Human Development. (Library of Congress Catalog Card No. 91-65608).

Cakmak, M. (2009). The perceptions of student teachers about the effects of class size with regard to effective teaching process. *The Qualitative Report, 14*(3), 395.

Carmean, C., & Haefner, J. (2002). Mind over matter: Transforming course management systems into effective learning environments. *EDUCAUSE Review, 37*(6), 26-34.

Detlor, B., Booker, L., Serenko, A., & Julien, H. (2012). Student perceptions of information literacy instruction: The importance of active learning. *Education for Information, 29*(2), 147-161.

Drew, V. & Mackie, L. (2011). Extending the constructs of active learning: Implications for teachers' pedagogy and practice. *Curriculum Journal, 22*(4), 451-467.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D, & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, 103-120.

Fata-Hartley, C. (2011). Resisting rote: the importance of active learning for all course learning objectives. *Journal of College Science Teaching, 40*(3), 36.

Felder, R. M., Brent, R., Prince, M. (2011). Engineering Instructional Development: Programs, Best Practices, and Recommendations. *Journal of Engineering Education, 100*, 89-122.

Foreman, J. (2003). NEXT- generation: Educational technology versus the lecture. *EDUCAUSE Review, 38*(4), 12-22.

Froyd, J. E. & Ohland, M. W. (2005). Integrated Engineering Curricula. *Journal of Engineering Education*, 147-164.

Guzdial, M., Ludovice, P., Realff, M., Morley, T., Carroll, K. & Ladak, A. (2001). The Challenge of Collaborative Learning in Engineering. *Institute of Electrical and Electronics Engineers*, 24-29.

Hsieh, C. & Knight, L. (2008). Problem-based learning for engineering students: An evidence-based comparative study. *Journal of Academic Librarianship, 34(*1), 25-30.

Huba, M. E. & Freed, J. E. (2000). *Learner –centered assessment on college campus: Shifting the focus from teaching to learning.* Needham Heights, MA: Allyn & Bacon.

Iowa State University. (2013). Retrieved from http://www.ir.iastate.edu/factbk.html.

Karplus, R. & Their, H.D. (1969). *A new look at elementary school science*. Chicago: Rand McNally & Company.

Kim, K., Sharma, P., Land, S., & Furlong, K. (2013). Effects of active learning on enhancing student critical thinking in an undergraduate general science course. *Innovative Higher Education, 38*(3), 223-235.

Kotru, S., Burkett, S. L., & Jackson, D. J. (2010). Active and collaborative learning in an introductory electrical and computer engineering course. *The Journal of General Education, 59*(4), 264-272.

Laws, P., Sokoloff, D., & Thornton, R. (1999). Promoting active learning using the results of physics education research. *UniServe ScienceNews, 13.*

Leng, Y., Xu, X., & Qi, G. (2013). Combining active learning and semi-supervised learning to construct SVM classifier. *Knowledge-Based Systems, 44*, 121-131.

McClain, A. R. & DeLoatch, S. J. (2005). Successful Interventions for Engineering Student Retention. *Norfolk State University*, 1-7.

Magno, C. (2010). *The role of metacognitive skills in developing critical thinking*. Retrieved from http://academia.edu/1911392/The_Role_of_Metacognitive skills_in_Developing_Critical_Thinking.

Marek, E. A., Cowan, C. C, & Cavallo, A. M. (1994). Student's misconception about diffusion: How can they be eliminated? *American Biology Teacher, 56*, 74-78.

Myllymaki, S. (2012). Cooperative learning in lectures of an advanced electrical engineering course. *International Journal of Electrical Engineering Education, 49*(2), 146-156.

Orr, M., Benson, L., & Biggers S. (2008). Student study habits and their effectiveness in an integrated statics and dynamics class. *Annual Meeting of the American Society for Engineering Education*, Pittsburg, PA.

Pierce, C. E., Gassman, S. L., & Huffman, J. T. (2013). Environments for fostering effective critical thinking in geotechnical engineering education (Geo-EFFECTs). *European Journal of Engineering Education, 38*(3), 281-299.

Prince, M. J. & Felder, R. (2004). *Inductive teaching and learning methods: Definitions, comparisons, and research bases*. Retrieved from http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/InductiveTeaching.pdf.

Rahmat, R. A. & Aziz, N. A. (2012). Stimulating learning ownership to engineering students via learning contract. *Asian Social Science, 8*(16), 57-64.

Rowland-Bryant, E., Skinner, A. L., & Dixon, L. (2011). Using relevant video clips from popular media to enhance learning in large introductory psychology classes: A pilot study. *Journal on Excellence in College Teaching, 22*(2), 51-65.

Rutz, E., Eckart, R., Wade, J., Maltbie, C., Rafter, C., & Elkins, V. (2003). Student performance and acceptance of instructional technology: Comparing technology-enhanced and traditional instruction for a course in statics. *Journal of Engineering Education, 92*(2), 133-140.

Sargent, L. D., Allen, B. C., & Frahm, J. A. (2009). Enhancing the experience of student teams in large classes: Training teaching assistants to be coaches. *Journal of Management Education, 33*(5), 526-552.

Schneider, L.S. & Renner, J. W. (1980). Concrete and formal teaching. *Journal of Research in Science Teaching, 17*, 503-517.

Scott, S. (2011). Contemplating a constructivist stance for active learning within music education. *Arts Education Policy Review, 112*(4), 191-198.

Slavin, R. (1991). Synthesis of research on cooperative learning. *Educational Leadership, 48*(5), 71-81.

Steif, P. S. & Dollar, A. (2008). An interactive, cognitively, informed, web-based statics course. *International Journal of Engineering Education, 24*(6), 1229-1241.

Stephans, J., Dyche, S., & Beiswenger, R. (1988). The effect of two instructional models in bringing about a conceptual change in the understanding of science concepts by prospective elementary teachers. *Science Education, 72*, 185-196.

Stephen, C., Ellis, J., & Martlew, J. (2010). Taking active learning into the school: A matter of new practices? *International Journal of Early Years Education, 18*(4), 315-329.

Thomas, S., Subramaniam, S., Abraham, M., Too, L., & Beh, L. (2011). Trials of large group teaching in Malaysian private universities: A cross sectional study of teaching medicine and other disciplines. *BMC Research Notes, 4*, 337.

Turns, J., Atman, C. J., Adams, R., & Barker, T. (2005). Research on Engineering Student Knowing: Trends and Opportunities. *Journal of Engineering Education*, 27-40.

Vallim, M. B., Farines, J., & Cury, J. E. (2006). Practicing engineering in a freshman introductory course. *IEEE Transactions on Education, 49*(1), 74-79.

Vest, C. M. (2008). Context and Challenge for Twenty-First Century Engineering Education. *Journal of Engineering Education*, 235-240.

Walker, J. D., Cotner, S., & Beermann, N. (2011). Vodcasts and captures: Using multimedia to improve student learning in introductory biology. *Journal of Educational Multimedia and Hypermedia, 20*(1), 97-111.

Wanous, M., Procter, B., & Murshid, K. (2009). Assessment for learning and skills development: The case of large classes. *European Journal of Engineering Education, 34*(1), 77-85.

Yazedjian, A & Kolkhorst, B. B. (2007). Implementing small-group activities in large lecture classes. *College Teaching, 55*(4), 164.

Zorn, J. & Kumler, M. (2003). Incorporating active learning in large lecture classes. *California Geographer, 43*, 50-54.

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