

A Case For a Reform in Teaching Introductory, Fundamental Engineering Mechanics Courses

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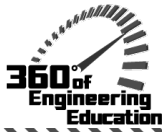
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ABSTRACT

Introductory, fundamental engineering mechanics (IFEM) courses, such as statics of engineering, mechanics of materials, dynamics, and mechanics of fluids, have far too long been focused on intense mathematical and theoretical concepts. Bold new methodologies that connect science to life using active learning pedagogies need to be emphasized more in engineering classrooms. This study investigated the role of a new paradigm in teaching IFEM courses and attempts to contribute to the current national conversation in engineering curriculum development of the need to change engineering education—from passive learning to active learning. Demographic characteristics in this study included a total of 4,937 students, of whom 4,282 (86.7%) are males and 655 (13.3%) are females, over a period of seven years, from 2006 to 2013. The students' majors included aerospace engineering, agricultural engineering, civil engineering, construction engineering, industrial engineering, materials engineering, and mechanical engineering.

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

The principal focus of this work was to formulate a convincing argument using data accumulated over seven years that a new paradigm utilizing student-centered pedagogies in teaching IFEM courses should be more emphasized to move engineering curriculum towards a more active and student-centered state. After evaluating the effects of several variables on students' academic success, the results may provide important information for both faculty and researchers and present a convincing argument to those faculty interested in a reform but hesitant to abandon conventional teaching practices. By promoting this 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 disciplines⁴⁰. The focus of the new paradigm was using 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 inquiry¹⁸. 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 who were taught traditionally^{4,26, 42}.

Traditionally-taught students are understood as those whose instruction primarily focuses on verbal and printed words, rote memorization, and is instruction driven³⁸. Students who are taught traditionally are told what they are expected to know and concepts are presented deductively^{10,16}, where the instructor 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 learning³⁰.

This quantitative study was designed to explore variables affecting student academic success, 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 to an *experimental pedagogy*, which is the 50-minute, three times a week class centered on active learning. The variables included demographic characteristics and grades earned in class. This study was conducted using data over a period of seven years—from 2006 to 2013—in statics of engineering (EM 274) at Iowa State University (ISU) from multiple instructors teaching multiple sections.

Statics of engineering was chosen because its concepts and applications are needed in almost every discipline of engineering^{6,33}. 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^{5,28}. Many researchers^{5,6,28,33} 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^{43,46}, humans think, learn, and solve problems by making connections and associations to previous experiences. Numerous researchers^{13,43,46} 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 generally, and its curriculum development more specifically.

LITERATURE REVIEW

A. Introduction: Creating a Meaningful Curriculum in Introductory, Fundamental Engineering Courses

The major emphasis on curriculum development in engineering education since the early 1970s has been on the implementation process of how to teach our engineering students better^{9,31,44}. To this day, curriculum development in engineering education has continued to be a pressing problem that will require our best thinking and perhaps a stronger collective movement into a new and different form of teaching engineering classes, particularly IFEM classes. Numerous discussions in IFEM courses have focused on the teaching delivery^{2,7,23,37} and what would make a meaningful curriculum^{1,9,35}. From policy makers, to curriculum specialists, to university

educators, and to parent groups, people have been trying to decide on the best way to teach students. Discussions have revolved around project-based learning, case-based learning, discovery learning, and just-in-time teaching with three instructional approaches of active learning, cooperative learning, and problem-based learning³⁰.

Decades ago, the education philosopher, Dewey¹¹, suggested a profound curriculum change. Dewey believed that all genuine education comes from experience and spoke of two forms of education—traditional and progressive. Dewey argued that every experience lives on in further experiences and that traditional education offers the type of experiences that are not genuine, whereas progressive education insists upon the quality of the experience. The type of curriculum Dewey recommended does not come from “experts” outside the classroom; but is to be created with the instructor and students inside the classroom.

Emphasizing on Dewey’s principles, several other scholars emerged within the last two decades ago. Alwarger and Flores³ suggested that “learners (both instructor and students) should be at the center of learning, asking critical questions, engaging in meaningful problem-posing and problem-solving, and creating and recreating knowledge”. Harste¹⁵ stated that curriculum is a meaning-making potential where knowledge is created, acted upon, and recreated at the point of experience, and that it provides opportunities for both instructor and students to experience themselves as learners, engaged together in inquiry to create, critique, and transcend their present knowledge.

Numerous other scholars of engineering education^{22,23, 29, 34}, who have emerged within the past decade, have built upon Dewey and his contemporaries’ recommendations, from the previous century, that active, cooperative, problem-based learning is the theme to be suggested when discussing a new curriculum development for introductory, fundamental engineering classes. The theme strongly suggests that instructor and students work together to create new understandings²⁹. In this new approach, learners would be able to make choices and form their own perspective on ideas that are important to them and possess freedom to think, observe, and ask questions³⁴. The researchers of this study wish to transfer the concept of this “new learning” and investigate that when instructor and students in IFEM courses participate in a curriculum that is generated by active and cooperative learning, as suggested by Dewey and numerous other scholars, does a stronger development of student learning in engineering concepts occur?

B. Role of the Instructor in Developing a New Curriculum in Engineering Education

The different roles assumed by faculty members reflect the type of curriculum used in the engineering classrooms. Some instructors enjoy the authoritarian stance and provide students the traditional education³⁸. In the traditional education format students are told what they are expected to know and concepts are presented deductively^{10,16}. Other instructors become too laissez-faire and become a silent member of the classroom or mainly an observer—where instruction primarily allows students to grow and learn on their own with little or no extrinsic help²⁵.

The role of the instructor in the classroom for course development in engineering education cannot be divorced from the understanding of theories of learning and the effectiveness of

student learning. To understand the complex process of learning, theories about human learning can be categorized into six broad paradigms: behaviorism, cognitivism, constructivism, experiential, humanistic, and social-situational learning theories³⁹. 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^{12,20,41,45}. Out of the six paradigms, researchers^{19,20,41} believe that constructivism aligns best with engineering education. It is a theory of learning founded on the premise that a learner's knowledge comes from his/her previous knowledge, much like the purposeful, reflective, and methodical nature of engineering. There are several guiding principles of constructivism^{14,20,24,36,41}:

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.

The literature suggests that a change in the development of curriculum in teaching IFEM courses is worth exploring. When compared to implementation strategies of learning theories, the active learning model combined with the cooperative learning model, in line with the constructivism view, appears to provide a strong framework for fostering the development of student understanding of fundamental engineering concepts—the researchers of this study wish to explore this structure of learning for IFEM courses.

RESEARCH QUESTIONS

This study sought to answer the research questions:

- 1) *Do constructivist pedagogies improve student ability to understand course concepts and learn problem-solving measured through final class grades?*
- 2) *Do constructivist pedagogies using different levels of interventions improve student performance measured through comparisons of final class grades of different cohorts taught by a single faculty member?*

METHODOLOGY

A. 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 engineering¹⁷. The population, from which the respondents were drawn, are students enrolled in statics of engineering (EM 274) classes from Fall 2006 to Spring 2013. The sample consisted of a total of 4,937 students, of whom 4,282 (86.7%) are males and 655 (13.3%) are females. The students' majors included: aerospace engineering, 776 students (15.7%); agricultural engineering, 208 students (4.2%); civil

engineering, 792 students (16.0%); construction engineering, 492 students (10.0%); industrial engineering, 372 students (7.5%); materials engineering, 251 students (5.1%); and mechanical engineering, 1,732 students (35.1%). There were 314 students (6.4%) who were enrolled outside the majors mentioned above.

B. Design and Procedure

Passive learning featured in this study is the typical lecture format, wherein the faculty member 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 interactions among students during class time.

Active learning, on the other hand, as 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 over the period of seven years—from Fall 2006 to Spring 2013: 1) undergraduate students at ISU who were enrolled in the traditional (passive learning) statics of engineering classes from Fall 2006 to Spring 2013, and 2) undergraduate students at ISU who were enrolled in the experimental (active learning) pedagogy statics of engineering classes from Fall 2006 to Spring 2013.

Anticipating questions regarding variability, both the passive learning classes and the active learning classes shared identical syllabus, grading schema, homework problems, and examination questions. This procedure was rigorously repeated each semester throughout the study from Fall 2006 to Spring 2013. Although homework and examination problems were graded by numerous teaching assistants each semester, a standard grading policy and outline were used to aid in uniformity and consistency in grading (minimizing variability in grading).

Independent Variable

The independent variable used in this study is *type of class*—traditional, passive learning class versus experimental, active learning class.

Dependent Variable

The dependent variable used in this study is *final class grade*.

A student database was obtained from the Office of the Registrar at ISU. One of the authors of this paper taught the experimental, student-centered pedagogy classes continuously each semester from Fall 2006 to Spring 2013. Multiple (ten) members of the faculty from the aerospace engineering department at ISU taught the traditional, teacher-centered pedagogy classes from Fall 2006 to Spring 2013.

C. Data Analysis

This study employed an independent samples *t*-test, a nonparametric independent samples test, and a general linear univariate model analysis to understand the outcome of student learning effectiveness concerning the impact of learning interventions using student-centered pedagogy on their academic learning.

The traditional (passive, teacher-centered pedagogy) classes involved full 50-minute lectures with no interruptions, other than occasional questions from students. On the other hand, the experimental (active, student-centered pedagogy) classes involved interventions including supplemental videos and interactive-teaching style (active, student-centered learning pedagogy), using think-pair-share, one-minute muddiest point, peer teaching, and problem solving in groups³⁰. Supplemental videos were created by one of the authors of this paper using Corel Painter 12 and Camtasia. Each video is no longer than 8-10 minutes where it re-emphasizes important points of materials being discussed in class. The order of activities was changed from lecture to lecture for the active learning classes such that students would enter class with a sense of anticipation. These activities are the conceptual backbone that shapes the pedagogy (constructivism theory of learning) used in the active, experimental classes. Constructivism strongly encourages instructors to be aware of their students' capacities and needs and agrees much with Dewey¹¹ and numerous other scholars^{22,23, 29, 34} mentioned earlier in this paper that: 1) learning is social, 2) learners need choices to connect to personal experiences, and 3) learning is active and reflective.

Quantitative data collection was employed, which allowed the data to be analyzed using statistical analysis procedures provided in SPSS statistical software. 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 process ensures that the researchers of this project cannot identify the individuals to whom the data pertain. An exempt classification for the human subjects research office was obtained from the ISU Institutional Review Board.

Active learning pedagogies, which involved think-pair-share, one-minute muddiest point, peer teaching, and problem solving in groups for the experimental pedagogy classes, were introduced since the beginning of the research in 2006. Supplemental videos were added as active learning interventions in 2011.

RESULTS AND DISCUSSIONS

Before performing any formal statistical data analysis, a histogram of the dependent variable was examined to confirm normality. Normality assumptions were not met. Thus the independent samples *t*-test was validated using a nonparametric independent samples test and using a general linear univariate model analysis.

Out of the 4,937 cases analyzed in this study, 315 cases (6.38%) were missing data on pre-college performances. Missing data are frequently encountered and occur in all types of studies, no matter how strictly designed or how hard investigators try to prevent them^{8,21,27,32}. When predictors and outcomes are measured only once (such as in this study), *multiple imputation of missing values* is the advocated approach^{21,32}. In this study, most of the missing data (particularly high school grade point average, American College Testing scores and Scholastic Aptitude Test scores) were highly associated with international students; thus trimming the original data set was not an option, to avoid reducing the sample size in favor of U.S. students. The multiple imputation approach executed in SPSS conveniently ran simulations and searched for patterns in the available data set by creating a probability-based judgment as to what the missing data would likely be and replace them to create a full data set. In this study, five imputations were used and they were performed in sequence. This study presents only results of the fifth imputation.

For the first research question, comparisons between the 2 groups (traditional versus experimental) were performed, which included: pre-college performances, descriptive statistics, and comparison of means to determine whether there is a difference between the 2 groups. Each analysis is described below:

Pre-college performances were compared between the 2 groups and the analysis shows no statistically significant difference in means of pre-college variables, which included high school grade point average; American College Testing (ACT) subject scores in English, Mathematics, and the Composite ACT; Scholastic Aptitude Test (SAT) scores in Verbal and Mathematics subject scores. These results show that students in both groups essentially started at the same level entering college.

A summary of descriptive statistics (N, mean, and standard deviation) of the dependent variable by class type is seen in Table 1. The table shows that the experimental class (active, student-centered learning pedagogy) has a mean greater than that of the traditional class (passive, teacher-centered learning pedagogy), and the standard deviation of the experimental class is less than that of the traditional class. The mean shown in the results summarized in Table 1 is out of a 4.00 scale.

Table 1
Descriptive Statistics of Independent Variable

	class type	N	M	SD
final class grade	experimental	2293	3.09	1.002
	traditional	2644	2.85	1.149

An independent samples *t*-test was conducted to determine if there was a difference in student performance in statics of engineering, as measured from class grade between students taught using the active, student-centered approach and students taught using the passive, teacher-centered approach over the period of seven years, from 2006 to 2013.

The results show that there was a statistically significant difference in final class grade between the experimental, active, student-centered class ($M=3.09$) and the traditional, passive, teacher-centered class ($M=2.85$); $t(4934.843)=7.987, p < .001$ as seen in the results summarized in Table 2, and that student-centered pedagogy does have an effect on student.

Table 2
Independent Samples t-Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		<i>F</i>	<i>p</i>	<i>t</i>	<i>df</i>	<i>p</i> (2-tailed)	Mean Difference	Std. Error of Difference	95% Confidence Interval of the Difference	
									Lower	Upper
final class grade	equal variances assumed	57.615	.000	7.910	4935	.000	.24443	.03090	.18385	.30501
	equal variances not assumed			7.987	4934.843	.000	.24443	.03060	.18443	.30442

Due to violations of normality when examining the histogram of the dependent variable, the results of the independent samples *t*-test were validated using a nonparametric independent samples test, as shown in Figure 1. Again results show that indeed there is a statistically significant difference in student performance as measured through final class grade.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of final class grade is the same across categories of type of class .	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 the dependent variable.

Furthermore, a general linear univariate model analysis was estimated, and again validated the results of the independent samples *t*-test and of the nonparametric independent samples tests that there was a statistically significant difference ($p < .001$) found between the traditional, active, student-centered class and the passive, teacher-centered class, as seen in the results summarized in Table 3—the tests of between-subjects effect table of class type.

Table 3
Tests of Between-Subjects Effects of Class Type
 Dependent Variable: final class grade

Source	Type III Sum of Squares	<i>df</i>	Mean Square	<i>F</i>	<i>p</i>	Partial Eta Squared	Noncentrality Parameter	Observed Power ^b
corrected model	73.367 ^a	1	73.367	62.570	.000	.013	62.570	1.000
intercept	43324.388	1	43324.388	36948.237	.000	.882	36948.237	1.000
type of class	73.367	1	73.367	62.570	.000	.013	62.570	1.000
error	5786.632	4935	1.173					
total	49150.065	4937						
corrected total	5859.999	4936						

a. R Squared = .013 (Adjusted R Squared = .012)

b. Computed using alpha = 0.05

Finally, to answer the overarching second research question of this study—*do constructivist pedagogies using different levels of interventions improve student performance measured through comparisons of final course grades of different cohorts taught by a single faculty member?*—a general linear univariate model analysis of years was estimated to investigate the different comparisons of cohorts taught using the experimental, student-centered pedagogy, as seen in the results summarized in Table 4.

Table 4
Tests of Between-Subjects Effects of Years
 Dependent Variable: final class grade

year	<i>M</i>	<i>SD</i>	95% Confidence Interval	
			Lower Bound	Upper Bound
2006	2.75	.100	2.555	2.948
2007	3.05	.046	2.963	3.142
2008	3.16	.053	3.058	3.264
2009	2.90	.064	2.774	3.024
2010	3.05	.040	2.972	3.129
2011	3.27	.054	3.165	3.378
2012	3.14	.100	2.946	3.337
2013	3.56	.115	3.337	3.789

type of class = experimental

Also, a summary of results as seen in Table 5 shows that, in comparison to the cohort of 2013, there is a statistically significant difference in student performance each year throughout the study, except with cohorts in 2011 and 2012. There is no statistically significant difference between the 2013 cohort compared to the 2011 cohort and also between the 2013 cohort compared to the 2012 cohort. This might be due to the fact that supplemental videos were added as interventions of active learning in 2011; for the last three years of the research (2011, 2012, and 2013) all cohorts in the experimental, active, student-centered classes experienced full injections of interventions—which involved the full usage of active learning pedagogies of think-pair-share, one-minute muddiest point, peer teaching, and problem solving in groups, and supplemental videos. Thus, no statistically significant differences in student performance between the 2013 cohorts compared to the 2011 cohorts and also between the 2013 cohorts compared to the 2012 cohorts were expected. The summary of results in Table 5 confirmed this finding.

Table 5

Multiple Comparisons^a

Dependent Variable: final class grade

Bonferroni

(I) year	(J) year	Mean Difference (I-J)	Std. Error	<i>p</i>	95% Confidence Interval	
					Lower Bound	Upper Bound
2013	2006	.8116*	.15277	.000	.3338	1.2894
	2007	.5109*	.12403	.001	.1230	.8988
	2008	.4025*	.12671	.042	.0062	.7987
	2009	.6638*	.13177	.000	.2517	1.0759
	2010	.5130*	.12205	.001	.1313	.8946
	2011	.2915	.12742	.623	-.1070	.6900
	2012	.4216	.15244	.160	-.0551	.8984

type of class = experimental

LIMITATIONS OF STUDY

The results of this study were as expected and were supported by the review of 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 representation of overall college student populations. The gender ratio strongly favored males, with 4,282 (86.7%) males and 655 (13.3%) females. Although the gender ratio is considerably less females than the campus

as a whole (44%) and less than the majority female population of academic nationally, the sample gender distribution more closely reflects the representation of female students within engineering majors.

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 over seven years—from Fall 2006 to 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.
6. There may be limited generalizability and a potential for bias from the findings of this study due to the absence of a 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 to teaching assignments assigned by the department administrators.

Due to these 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 was a difference in student performance in IFEM classes of statics of engineering between the traditional, teacher-centered, 50-minute, three times a week classes (passive learning) and the experimental, student-centered pedagogy, 50-minute, three times a week classes, that involved interventions including supplemental videos and interactive-teaching style (active learning) as escalation of active-learning interventions were injected from one cohort to the next. The results as tested using an independent samples *t*-test and validated using a nonparametric independent samples test and a general linear univariate model analysis, overwhelmingly showed that there was a statistically significant difference between classes taught passively using the teacher-centered pedagogy and classes taught actively using the student-centered pedagogy, as summarized below:

1. The type of class (traditional or experimental) does predict performance across course grades in statics of engineering.
2. High levels of interventions, which involved the full usage of active learning pedagogies of think-pair-share, one-minute muddiest point, peer teaching, and problem solving in groups, and supplemental videos of active learning are associated with a statistically significant difference in learning compared to lower levels of interventions of active learning in statics of engineering in the experimental classes.

RECOMMENDATIONS TO FACULTY AND FUTURE RESEARCHERS

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 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 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 IFEM classes with critical thinking in upper-level major classes.
9. Further study is needed to explore effects of active learning on gender and ethnicity.

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