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Self-Assessed Student Learning Outcomes in an Engineering Service Course*

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Michigan State University (MSU) received a grant from the GE Fund to reform the early undergraduate engineering learning experience. Focusing on the key service course in Electrical and Computer Engineering (ECE 345), this project developed and implemented over a six-year period a new section based on innovative instructional approaches, including cross-disciplinary experiences in teamwork, design, and the use of advanced teaching technologies. This paper compares student self-assessed outcomes from these innovative sections with those from traditional sections of the course. Results support a central tenet of active and collaborative instruction, namely that student involvement in their own learning significantly improves self-assessed learning outcomes.

INTRODUCTION

ENGINEERING SCIENCE service courses represent the initial exposure to engineering for many students. They also form the foundation for degree requirements in undergraduate engineering majors. These courses serve students from many different engineering majors, challenging instructors and teaching assistants (TAs) to meet the needs of students with different levels of preparedness. At the same time pressure has been brought to bear by faculty and industry representatives to include more material and enhance students' teamwork and communication skills. With addressing these issues in mind, several engineering and education faculty members at Michigan State University (MSU) sought to improve the learning experience of undergraduates in the key Electrical and Computer Engineering service course, Electronic Instrumentation and Systems (ECE 345), by revising course content and using innovative instructional approaches. These changes were developed, initiated, and assessed over a six-year period. This paper compares the effectiveness of student self-reported outcomes for innovative sections of ECE 345 with the more traditional sections of the course.

REFORMING ECE 345: ELECTRONIC INSTRUMENTATION AND SYSTEMS

'ECE 345: Electronic Instrumentation and Systems' is a service course at MSU open to all undergraduate engineering majors, except electrical engineering (EE) and computer engineering (CpE) majors. It is a three-credit course with two 50-minute lectures and one three-hour laboratory period per week. The course is offered in the fall, spring and summer semesters and has a total annual enrollment of approximately 400 students. This represents between 10 an 15% of the total student-credit hours (SCH) generated by all MSU ECE-coded courses annually. Students are introduced to electrical and electronic components, circuits and instruments. The circuit laws are applied to dc, ac, and transient circuit applications. Students are also introduced to digital logic fundamentals and gain experience in designing, building and testing simple logic circuits. A three-hour/week laboratory provides an active-learning experience for the students.

The field of electronic instrumentation and systems has developed dramatically in the past several years, primarily because of rapid advances in computer and integrated-circuit technology. Moreover, this body of material has become increasingly important to an ever-widening circle of practicing engineers. One need only look at the changes that have taken place in the automobile, where crude mechanical controls have given way to sophisticated electromechanical monitoring and control systems. The educational challenges associated with keeping a course such as ECE 345 modern has become a daunting task.

At MSU, ECE 345 serves all departments except Electrical and Computer Engineering. For most departments, ECE 345 represents a 'general breadth requirement,' although Mechanical Engineering expects ECE 345 to feed directly into its course on control systems. Some departments list ECE 345 as one of three or four courses from which the student must choose. This variation in expectation means that few departments are currently prepared to take advantage of the student learning experiences in ECE 345 because they have not identified where this learning experience fits with their curricula. In addition, the breadth of service exerts considerable pressure on

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the faculty teaching ECE 345 to include a large amount of material; i.e. every department wants some of its content and instructional issues included. Despite the pressure to add new material in both lectures and laboratory experiences in keeping with changes in the field (e.g. analog to digital), few department chairs or their faculty seem willing to remove older material from ECE 345.

The redevelopment of ECE 345 occurred in two phases. Working together, in phase one interested faculty members from engineering and education interviewed key administrators and faculty in the College of Engineering to determine the perception of ECE 345 as it relates to course goals and content, benchmarked similar service courses at other institutions, and observed students enrolled in ECE 345 to gain a better understanding of their expectations and concerns about the course. Phase two focused on making specific changes to instructional approaches and assessing the effectiveness of these reforms.

Phase one reforms

Activities during phase one led to the redevelopment of learning objectives, course goals and content, and identification of new topics. New course learning objectives and course goals included to:

- convey core knowledge related to electrical engineering fundamentals;
- convey core knowledge related to electronic instrumentation and instrumentation systems, including embedded computers;
- convey essential information related to electrical safety;
- strengthen math skills through engineering applications;
- strengthen and expand computer skills through engineering applications;
- enhance problem-solving skills;
- enhance multidisciplinary teaming skills, including communication skills; and
- provide experiences and content relevant to subsequent senior design projects that deploy modern applications of electronic instrumentation and instrumentation systems, including embedded computers.

From this preliminary set of course learning objectives and goals, participating faculty members and TAs developed a tentative set of specific electrical and computer engineering topics in the context of their application in engineering system design, analysis and testing. These included:

- electric energy and signal sources;
- circuit-analysis fundamentals;
- resistors, capacitors, inductors, transformers and operational amplifiers;
- sensors (transducers and their electrical interfaces), annunciators and actuators;
- representation of analog signals and the principle of signal processing (e.g. detecting, amplifying, filtering and transforming real-time electrical signals derived from transducers into useful information);
- representation of discrete signals and the principle of signal processing (e.g. signal conditioning with amplifiers, comparators and Schmitt triggers; event counting, period between events and frequency of events);
- transformation of information between its analog and digital representations (e.g. A-to-D and D-to-A conversion), including sampling rates and quantization error;
- the properties and proper use of electronic test and measurement equipment, including the application of embedded computers;
- hierarchical modeling of electronic instrumentation systems (components, subsystems and subsystem interfaces); and
- course capstone applications of electronic instrumentation and systems (to be threaded throughout the course): mechanics and mechanical engineering; chemical engineering; civil engineering; materials science; and agricultural engineering/biosystems engineering.

Phase two reforms

Course reform efforts in the second phase focused on instruction with the following primary objectives:

- to focus the course learning objectives on the students' educational needs;
- to improve the quality of the course; and
- to improve the efficiency of course delivery and justify resources needed for the course.

Instructional innovations drew from the extensive literature on active and collaborative learning. Although active and collaborative learning are often used synonymously, they are not identical. Active learning is an overarching term that encompasses a range of pedagogical methods and approaches; collaborative learning is one of these methods. Definitions of active learning vary but common to most definitions is the notion that active learning involves student participation in the learning process. That is to say, active learning requires students to be engaged in a dynamic fashion, not as passive listeners [1–5]. Collaborative learning is similar, in that students need to be engaged in the process, but collaborative learning also requires that this take place between structured groups of students [6–7].

In their omnibus review of the literature on the effects of college on students, Pascarella & Terenzini [5] found collective evidence that active student engagement in their own education is positively related to outcomes. This approach has also been promoted in engineering education publications many times over the past decade [8–11].

Activities such as small-group discussion, cooperative learning activities, and peer-to-peer teaching have proven to increase student understanding and application of classroom material [4, 9, 12, 13]. These methods have also been found to produce higher-order cognitive and problem-solving skills [2, 7], an important outcome when seeking to train design engineers.

In the past decade, evidence about the benefits of active and collaborative instruction in engineering education has emerged. Felder and Brent [10, 14] propose specific collaborative and active instructional techniques to equip engineering students with skills and outcomes required by ABET. Their outline of teaching methods includes use of problem-based learning, student reporting of group findings, and using open-ended experiments for which 'the students would be given an objective (determine a physical property, establish an empirical correlation, validate or refute a theoretical prediction . . .), provided with enough training to keep them from destroying the equipment or injuring themselves, and turned loose.'

Other researchers have applied different active and collaborative teaching methods in engineering classes and reported on the perceived effectiveness of using these methods [9, 13, 15, 16]. Examples of these instructional methods include loosely structured hands-on laboratory activities, multidisciplinary design projects, brief hands-on activities during the traditional lecture, and use of peer-to-peer teaching during labs. Results include an increase in level of student satisfaction with the course, an increase in grade outcomes [16], increased conceptual understanding of material [9, 13], and improved learning and perception of the value of the specific course [15].

Also documented are specific ways in which these methods have been planned and assessed [8, 9, 10, 15, 16]. These assessments include, but are not limited to, faculty surveys and interviews, pre-, mid-, and post- surveys of student experiences, use of grade reports, and group process observations. With similar planning and assessment methods in mind, participating faculty members pursued the following tasks each semester to bring about incremental improvements in the course.

With these research findings in mind, participating faculty members pursued the following tasks each semester to bring about incremental improvements in the course:

- align the course learning objectives with the course instructional model;
- analyze the weekly scheduling of topics covered in the lecture and laboratory portions of the course and revise the course plan so that laboratory experiences reinforce topics covered in the lecture;
- revise the laboratory plan so that topics and skills introduced one week are reinforced in subsequent weeks;
- revise the laboratory exercises in order to align them with the course learning objectives;
- develop and share with the students at the beginning of the semester assessment tools used to evaluate their acquired knowledge and skills on the various course topics;
- eliminate tedious (redundant) exercises by having students divide into teams to complete all of the required tasks and then let team members describe to others what they have done and learned;
- improve student communication skills by better linking the laboratory manual with the requirements for their written laboratory reports;
- improve the sharing of information and encourage feedback about the course—including the course objectives, the course plan and outcomes assessment tools—with current students in the course, prospective students, and other constituent groups via the course website; and
- improve linkages between this course and advanced courses in the major.

Service courses such as ECE 345 tend to have very large enrollments, which can become overwhelming for the faculty called upon to teach such a course. This problem was addressed by developing some reusable instructional aids that could be used from semester-to-semester by the faculty teaching the course and their teaching assistants. These included the following.

Course-management software—Study participants and researchers developed a wide range of course-management software intended to improve the efficiency of managing large classes. This software was designed to track course enrollment, student attendance, homework scores, quiz scores, laboratory scores, exam scores, and the cumulative scores and final course grades throughout the semester. The software is flexible and can be modified to fit different course instructional models.

Reusable lectures—Course topics were decomposed into discrete, self-contained lectures. The new material was placed in PowerPoint presentations. These presentations were typically given at the beginning of the lecture. The remaining time in the lecture period was devoted to questions and answers and problem-solving exercises.

Reusable laboratory exercises—Laboratory experiences were altered and emphasis placed on student learning and outcomes assessment. This in turn permitted the laboratory exercises to be reused from semester to semester, while permitting continuous improvement to take place in the quality of the laboratory exercises. The laboratory manual was placed completely in MS Word format. Electronic versions of the laboratory manual's figures were made available to students so that they could use them in their formal laboratory reports.

Laboratory videos—Because of the large number of laboratory sections and a very diverse set of teaching assistants assigned to teach these labs, the training of TAs became quite a challenge. This effort was especially labor-intensive when a new faculty member was assigned to teach the course. Laboratory videos were developed to assist new TAs, although they still needed ongoing training. These videos were intended to assist the person delivering the lecture, the TAs assigned to teach the lab sections, and the students taking the course. By watching the video each week, the lecturer could better gauge students' needs for the lecture before attempting a particular experiment. Moreover, the lecturer could better balance the content of a lecture with material covered in the weekly videos. The TAs developed a better understanding about their instructional roles during a given laboratory period. The students taking the laboratory gained valuable insight into the purpose of each laboratory experiment.

Assessment instruments for course improvement—A complete set of reusable assessment instruments was developed (see the aforementioned ECE 345 website). The lead course ECE 345 instructor, other faculty, each TA, the students in the course, students who took the course previously, and employers of students who took the course can potentially provide feedback on ways to further improve the course. Outcomes from this feedback can be used to make adjustments in the course within the semester and to plan for long-term changes in the course.

Assessment instruments for student learning—Sample homework assignments, lecture exams, laboratory quizzes, etc., were developed and published to demonstrate the link between course learning objectives and the assessment of student learning. The faculty who teach this course in the future as well as future laboratory TAs would be encouraged to use these student-learning assessment tools as a guide as they develop their own specific exams, homework, quizzes, etc.

Reusable course website—All of the items described above (and much more) are contained at the course website, which itself has been designed to be reusable from semester to semester. A faculty member completely unskilled in web-based publishing would only need a trained undergraduate student for an hour a week to update the website during the semester.

EVALUATING THE EFFECT OF COURSE REFORMS ON SELF-ASSESSED STUDENT LEARNING

Research questions and methods

The assessment of the project course examined three questions:

- Research Question 1: Who takes ECE 345?
- Research Question 2: How strongly is instructional environment, particularly the active and collaborative approaches envisioned in the service course reforms, related to student self-reported learning outcomes?
- Research Question 3: How effective are the service course reforms in improving self-reported student learning outcomes?

The first question was examined with simple descriptive statistics and cross-tabulations. A correlation matrix was used to answer the second question. For the third research question, student self-assessed learning outcomes from innovative and traditional sections of ECE 345 were compared, respectively, using one-way and multivariate analyses of variance in combination with Tukey-Kramer HSD post-hoc tests of mean differences.

Survey instrument

Data were gathered using a paper survey distributed and collected at the conclusion of the course from spring 1999 to spring 2003. The instrument developed by Patrick Terenzini and colleagues at Penn State University was adopted to assess changes in student learning outcomes in the two target service courses. The survey, entitled 'Student Classroom Experiences' drew on recommendations from ABET (EC2000) and several national reports [17]. The survey instrument consisted of 69 questions, of which 11 asked general demographic and contextual questions.

The demographic/context section was followed by 25 questions about classroom experience answered using a five-point scale: 1 = never, 2 = occasionally, 3 = often, 4 = very often/almost always, N/A = not applicable. The next section asked 26 questions about the student's progress made in certain areas as a result of taking the course using a four-point scale: 1 = none, 2 = slight, 3 = moderate, 4 = a great deal. The third section included seven questions asking students to indicate the extent to which they may have changed in specific areas related to career plans as a result of taking this course. These questions were answered using a five-point scale: 1 = decreased greatly, 2 = decreased somewhat, 3 = not changed, 4 = increased somewhat, 5 = increased greatly. The final question asked for the student's expected course grade, using an eight-point scale: 1 = 4.0, 2 = 3.5, 3 = 3.0, 4 = 2.5, 5 = 2.0, 6 = 1.5, 7 = 1.0, 8 = 0.

STUDY VARIABLES

Study variables were grouped into four sections. The first section ascertained student demographic data, contextual data, and course-specific information. The second section included questions regarding instructional practices. Student self-assessment of learning outcomes comprised the third section. The last section was labeled 'student self-assessed progress on other outcomes'.

Student demographics, contextual data, and course-specific information

Student demographic and contextual data were gathered on eleven student characteristics: course number, semester/year enrolled, major, gender, race/ethnicity, year in school, self-reported Grade Point Average (GPA), degree expectation, hours worked per week, number of courses completed, whether or not the student was a transfer student, and whether or not the student came from another degree program into engineering. Student-reported majors included a list of twelve distinct majors in the College of Engineering and other/no response choice.

The degree of course innovation was based on the specific instructor and semester/year offered. We assigned ECE 345 course sections into three groups based on these descriptors: (1) innovative (using reformed pedagogy and content), (2) mixed (some innovative, some traditional instructional approaches), and (3) traditional.

Instructional practices

Four constructs addressed specific instructional practices, which when taken together make up what is termed 'instructional environment':

- good general pedagogy;
- evidence of collaborative or active learning;
- use of design and application; and
- classroom climate for gender, race and ethnicity.

Criteria for each of these categories are defined below. We formed a single scale for each construct based on an aggregated average of individual items. Each item was equally weighted in the aggregate score.

Good general pedagogy—This construct assessed the degree to which faculty engaged in general teaching methods and behaviors to promote student intellectual development. This assessment was made based on the average scale of eight items: assignments clearly explained, assignments and learning activities are clearly related to one another, instructor makes clear expectations for student work, the instructor gives me frequent feedback on my work, the instructor gives me detailed feedback on my work, I'm encouraged to challenge the instructor's or other students' ideas, I interact with the instructor as part of this course, and I interact with the TA as part of this course.

Evidence of collaborative or active learning—This construct addressed specific teaching behaviors and curricular activities that supported student involvement and engagement in group learning activities. The scale score was the average across the following eight items: I work cooperatively with other students on course assignments, students teach and learn from each other, there are opportunities to work in groups, I discuss ideas with my classmates, I get feedback on my work or ideas from classmates, we do things that require students to be active participants in the teaching and learning process, the instructor guides students' learning activities rather than lecturing or demonstrating, and the instructor encourages students to listen/evaluate/learn from other students.

Use of design and application—This construct was based on the average of three items aimed at assessing how curricular constructions affect integrative thinking, an important part of engineering design and application. These items included: I'm encouraged to show how a particular course concept can be applied to an actual problem, I have opportunities to practice the skills I'm learning in the course, and the instructor emphasizes the design process and activities.

Classroom climate for gender and race/ethnicity—This construct averaged two items: students are treated the same whether white or a minority group member, and students are treated the same whether male or female.

Student self-assessed learning outcomes

The remaining constructs focused on self-reported student learning outcomes related to knowledge of the engineering profession, engineering design and problem-solving, analysis and assessment of solution alternatives, application and communication skills, and working with others. Consistent with recommendations in EC2000, seven constructs were created from individual items focused on student learning outcomes:

- knowledge of the engineering profession;
- engineering design;
- problem-solving;
- analysis and assessment of solution alternatives;
- application;
- communication skills; and
- working with others.

All criteria were equally weighted in forming scale scores.

Knowledge of the engineering profession—This construct was derived by averaging scores on two items: progress made because of this course in your understanding of what engineers do in industry or as faculty; and understanding of engineering as a field that often involves non-technical considerations.

Engineering design—This construct was the average score of three items: progress made because of this course in your knowledge and understanding of the language of design in engineering; knowledge and understanding of the process of design in engineering; and ability to 'do' design.

Problem-solving—This category was the average scale score of five items: progress made because of this course in your ability to identify what information is needed to solve a problem, divide problems into manageable components, develop several methods which might be used to solve a problem, understand that a problem might have multiple solutions, and use discussion strategies to analyze and solve a problem.

Analysis and assessment of solution alternatives—This construct was based on the average scale score of seven items: progress made because of this course in your ability to evaluate arguments and evidence so that the strengths and weaknesses of competing alternatives can be judged, use established criteria to evaluate and prioritize solutions, organize information to aid comprehension, ask probing questions that clarify facts/concepts/relationships, recognize contradictions or inconsistencies in ideas/data/etc., after evaluating alternatives develop a new alternative that combines the best qualities of previous alternatives, and recognize flaws in your own thinking.

Application—Two items were averaged for this construct: progress made because of this course in your ability to apply an abstract concept or idea to a real problem or situation, and identify the constraints on the practical application of an idea.

Communication skills—This construct was the average score of three items: progress made because of this course in your ability to clearly describe a problem orally, clearly describe a problem in writing, and explain your ideas to others.

Working with others—This construct was the average scale score of five items: progress made because of this course in your ability to be patient and tolerate the ideas/solutions proposed by others, develop ways to resolve conflict and reach agreement as a group being aware of the feelings of other members of the group, listen to the ideas of others with an open mind, and work on collaborative projects as a member of a team.

Student self-assessed progress on other outcomes

Consistent with EC2000 criteria, we also included five additional self-reported student learning outcomes:

- likelihood of becoming an engineer;
- responsible for own learning;
- retention in the engineering major;
- likelihood of continuing in graduate school; and
- expected course grade.

Each scale score was based on the average of a five-point scale from decreased greatly to increased greatly, applying unit weights to each item.

Likelihood of becoming an engineer—This construct was the average score of three items: as a result of this course your confidence in your ability to become an engineer has . . . , your motivation to become an engineer has . . . , and the likelihood that you will become a practicing engineer has . . .

Responsible for own learning—This construct is based on the score on a single item: your sense of being responsible for your own learning has . . . .

Retention in the engineering major—This outcome answers the question: the likelihood that you will continue in your engineering program has . . . .

Likelihood of continuing in graduate school—This construct answers the question: the likelihood that you will go on to graduate school in engineering has . . . .

Expected course grade—This item is reported on a scale from 1 (4.0) to 8 (0.0). We reversed the scale prior to correlation analyses to take the direction of the effect into account.

Limitations

This study is limited by its use of self-reported student outcomes. We chose these outcomes for three reasons. First, we wanted to focus on the complex learning outcomes related to EC2000 criteria, which are not adequately addressed by more traditional measures such as GPA. Second, we wanted to be consistent with previous work by Terenzini *et al* [17] to permit comparison with other findings. Finally, the variation in instructor practice made it problematic to compare more traditional outcomes, such as GPA.

RESULTS

Research question 1: Who takes ECE 345?

As shown in Table 1, institutional enrollment data and survey return rate data were gathered from spring 1999 to spring 2003 in ECE 345. During this period two faculty members taught ECE 345 in the traditional manner, four used a mixed (innovative and traditional) pedagogical approach, and three used innovative pedagogy exclusively. The total number of students enrolled was 1,621. The total number of respondents was 1,236. The return rate was 78%.

Although most engineering majors were represented in ECE 345, three fields dominated: mechanical engineering (n = 535; 46.6%), chemical engineering (n = 234; 20.4%), and engineering arts (n = 219; 19.1%). Of the sample of students who responded, 29.4% were female and 70.6% male. For ECE 345, 5.3% (63) self-identified as

Table 1. Enrollment and survey return rate

Semester	Actual Enrollment	Number of Respondents	Return Rate
Spring 1999	165	64	39%
Summer 1999	37	25	68%
Fall 1999	162	105	65%
Spring 2000	159	100	63%
Summer 2000	30	25	83%
Fall 2000	153	129	84%
Spring 2001	162	150	93%
Summer 2001	46	39	85%
Fall 2001	170	154	91%
Spring 2002	179	154	86%
Summer 2002	48	47	98%
Fall 2002	149	113	76%
Spring 2003	161	125	78%
Semester Not Reported	N/A	6	N/A
Total	**1621**	**1236**	**78%**

Black/African American, 0.9% (11) as Mexican-American/Chicano, 0.6% (7) Puerto Rican/Cuban/Hispanic, 0.1% (1) American Indian/Alaskan Native; 84.4% (998) White/Caucasian, and 2.4% (28) as Other.

Few freshmen and sophomores took ECE 345. Most students were in their junior (46.6%) or senior (49.5%) year. Many ECE 345 students intend to seek further education. Over 65% of respondents plan to seek a master's degree, and 11.2% a doctorate.

Students in ECE 345 ranged in their weekly work hours from 0 to 65. The majority ($n = 453$) worked between 10 and 20 hours a week (mean = 11.2; SD = 11.62). Four hundred and one students were not employed during the semester they took ECE 345. Students in ECE 345 ($n = 1{,}199$) reported a mean overall grade point average (GPA) of 3.29 (SD = 0.36).

Not reported are findings from three demographic variables because student respondents did not understand the items and/or answered them incorrectly. These measures included: 'Did you enter college at this university or transfer from another college/university?', 'Did you change majors from another degree program into engineering?', and 'Number of courses completed to date'.

Research question 2: How strongly is instructional environment, particularly the active and collaborative approaches envisioned in the service course reforms, related to student learning outcomes?

Table 2 shows the descriptive statistics for four Instructional Environment scales—Good General Pedagogy, Evidence of Collaborative/Active Learning, Use of Design/Application, and Gender/Race/Ethnicity Climate—and 12 EC2000-based self-reported learning outcomes. Table 3 shows that instructional environment is significantly related to self-reported student learning outcomes. For every learning outcome—knowledge of the engineering profession, design, problem-solving, analysis/assessment of solution alternatives, application, communication skills, working with others, likelihood of becoming an engineer, responsible for own learning, retention in the engineering major, likelihood of attending graduate school, and expected course grade—the higher the score on good general pedagogy, active/collaborative instruction, and use of design and application, the higher the student learning outcome. A positive classroom climate for women and minorities was positively related to 4 of the 12 outcomes, unrelated to the others. They held true across classroom designation (traditional or innovative).

These results strongly suggest that instructional approach made a difference in the self-reported learning outcomes of students in ECE 345. Use of sound pedagogical principles, emphasis on active and collaborative teaching and learning, incorporation of design, and fostering a climate where women and minorities feel welcome all positively affect student-learning outcomes. The results are not ambiguous: the classroom teacher and the instructional approaches he or she uses are strongly related to the amount and type of self-reported student learning. These findings support the claim that alternatives to the lecture format or transmission method of teaching will yield better learning outcomes.

These results are consistent with previous research on the use of active learning in the classroom. Student responses to comparable teaching modifications and pedagogical approaches in engineering courses also found an increase in the self-assessed increase in engineering skills such as design, problem-solving and application. Also, general knowledge of the profession and specific concepts increased with the active and collaborative learning experiences [9, 15, 16]. Similar gains in subject knowledge and critical thinking have been experienced in other disciplines when active

Table 2. Descriptive statistics: selected variables

Variable	Mean	Standard Deviation	N
Good General Pedagogy	2.5116	.59534	1082
Evidence of Collaborative or Active Learning	2.5419	.60962	1092
Use of Design and Application	2.4073	.68762	1140
Gender/Race/Ethnicity Climate	3.6596	.62821	1106
Knowledge of Engineering Profession	1.9658	.76691	1213
Design	2.2091	.73720	1194
Problem-solving	2.5567	.68315	1164
Analysis/Assessment of Solution Alternatives	2.3372	.69938	1156
Application	2.3890	.76110	1180
Communication Skills	2.3850	.77670	1181
Working with Others	2.4163	.82407	1160
Likelihood of Becoming an Engineer	3.2193	.63476	1193
Responsible for Own Learning	3.5426	.80730	1196
Retention in the Engineering Major	3.4610	.86333	1193
Graduate School	3.0794	.88854	1196
Expected Course Grade	2.1207	1.18416	1185

Table 3. Learning outcomes and instructional environment correlations

Learning Outcomes		Instructional Environment: Good General Pedagogy	Evidence of Collaborative or Active Learning	Use of Design and Application	Climate for Gender/Race/Ethnicity
Knowledge of Engineering Profession	Pearson Correlation	.377*	.331*	.421*	−.058
	Sig. (2-tailed)	.000	.000	.000	.056
	N	1073	1080	1130	1093
Design	Pearson Correlation	.430*	.377*	.515*	−.004
	Sig. (2-tailed)	.000	.000	.000	.884
	N	1058	1066	1118	1078
Problem-Solving	Pearson Correlation	.426*	.385*	.482*	.088*
	Sig. (2-tailed)	.000	.000	.000	.004
	N	1036	1042	1091	1051
Analysis/Assessment of Solution Alternatives	Pearson Correlation	.438*	.447*	.482*	−.009
	Sig. (2-tailed)	.000	.000	.000	.773
	N	1028	1037	1081	1043
Application	Pearson Correlation	.422*	.359*	.477*	−.013
	Sig. (2-tailed)	.000	.000	.000	.673
	N	1048	1054	1103	1065
Communication Skills	Pearson Correlation	.376*	.390*	.402*	−.011
	Sig. (2-tailed)	.000	.000	.000	.713
	N	1050	1056	1106	1065
Working with Others	Pearson Correlation	.350*	.462*	.395*	.011
	Sig. (2-tailed)	.000	.000	.000	.732
	N	1033	1041	1087	1051
Likelihood of Becoming an Engineer	Pearson Correlation	.365*	.296*	.359*	.078
	Sig. (2-tailed)	.000	.000	.000	.011
	N	1057	1063	1112	1074
Responsible for Own Learning	Pearson Correlation	.148*	.157*	.208*	.087*
	Sig. (2-tailed)	.000	.000	.000	.004
	N	1059	1065	1115	1077
Retention in the Engineering Major	Pearson Correlation	.238*	.226*	.270*	.058
	Sig. (2-tailed)	.000	.000	.000	.056
	N	1057	1063	1113	1074
Graduate School	Pearson Correlation	.199*	.172*	.201*	.055
	Sig. (2-tailed)	.000	.000	.000	.070
	N	1059	1065	1115	1077
Expected Course Grade	Pearson Correlation	−.191*	−.132*	−.180*	−.114*
	Sig. (2-tailed)	.000	.000	.000	.000
	N	1048	1057	1104	1066

* Correlation is significant at the 0.01 level (2-tailed).

and collaborative learning methods were employed [3, 7, 18].

Research question 3: How effective are the GE Fund service course reforms in improving self-reported student learning outcomes?

Irrespective of the faculty member teaching the course, when compared with the combination of mixed and traditional sections Table 4 shows that the innovative sections of ECE 345 were rated by students as having better general pedagogy ($F = 78.5$, $p < .000$, $df = 1, 1076$), use of collaborative/active instruction ($F = 12.3$, $p < .000$, $df = 1, 1087$), use of design and application ($F = 41.7$, $p < .000$, $df = 1, 1134$), and gender/race/ethnicity climate ($F = 3.7$, $p < .054$, $df = 1, 1101$).

Table 5 shows the mean comparisons for self-reported learning outcomes by category of instructional innovation. The innovative sections of ECE 345 scored significantly higher than the combination of mixed and traditional sections on 11 out of 12 self-reported learning outcomes as follows: knowledge of engineering profession ($F = 11.1$, $p < .001$, $df = 1, 1208$), design ($F = 20.7$, $p < .000$, $df = 1, 1189$), problem-solving ($F = 16.2$, $p < .000$, $df = 1, 1159$), analysis/assessment of learning alternatives ($F = 23.0$, $p < .000$, $df = 1, 1151$), application ($F = 26.9$, $p < .000$, $df = 1, 1175$), communication skills ($F = 8.8$, $p < .003$, $df = 1, 1176$), working with others ($F = 14.4$, $p < .000$, $df = 1, 1155$), likelihood of becoming an engineer ($F = 27.1$, $p < .000$, $df = 1, 1188$), responsible for own learning ($F = .9$, $p < .341$, $df = 1, 1190$), retention in the engineering major ($F = 7.0$, $p < .008$, $df = 1, 1188$), planning on going to graduate school in engineering ($F = 5.9$, $p < .015$, $df = 1, 1191$), and

Table 4. Instructional environment

Instructional Environment	Instructional Approach	N	Mean	Standard Deviation	Standard Error
Good General Pedagogy	Innovative	385	2.722	.5753	.0293
	Mixed and Traditional	693	2.398	.5740	.0218
	Total	**1078**	**2.514**	**.5947**	**.0181**
Evidence of Collaborative or Active Learning	Innovative	398	2.628	.5895	.0295
	Mixed and Traditional	691	2.494	.6166	.0234
	Total	**1089**	**2.543**	**.6100**	**.0184**
Use of Design and Application	Innovative	417	2.578	.6348	.0310
	Mixed and Traditional	719	2.310	.6984	.0260
	Total	**1136**	**2.408**	**.6878**	**.0204**
Climate for Gender/Race/ Ethnicity	Innovative	408	3.7071	.56462	.02795
	Mixed and Traditional	695	3.6317	.66207	.02511
	Total	**1103**	**3.6596**	**.62858**	**.01893**

expected course grade ($F = 13.1$, $p < .000$, $df = 1, 1180$). This result is a remarkable achievement given the variation in instructors, students, laboratory assistants, and so forth.

Learning outcomes did not vary significantly by student major. This result suggests that these curricular innovations and course assessment tools may be valuable across a variety of engineering disciplines. This suggestion is supported by the number of similar results found in other research

Table 5. Learning outcomes

Learning Outcomes	Instructional Approach	N	Mean	Standard Deviation	Standard Error
Knowledge of Engineering Profession	Innovative	441	2.063	.760	.036
	Mixed and Traditional	768	1.911	.766	.027
	Total	**1209**	**1.966**	**.767**	**.022**
Design	Innovative	435	2.336	.706	.033
	Mixed and Traditional	755	2.136	.746	.027
	Total	**1190**	**2.209**	**.738**	**.021**
Problem-Solving	Innovative	432	2.661	.647	.031
	Mixed and Traditional	728	2.495	.698	.025
	Total	**1160**	**2.557**	**.684**	**.020**
Analysis/Assessment of Solution Alternatives	Innovative	428	2.465	.663	.032
	Mixed and Traditional	724	2.262	.710	.026
	Total	**1152**	**2.337**	**.700**	**.020**
Application	Innovative	434	2.539	.711	.034
	Mixed and Traditional	742	2.303	.775	.028
	Total	**1176**	**2.390**	**.760**	**.022**
Communication Skills	Innovative	437	2.472	.755	.036
	Mixed and Traditional	740	2.333	.786	.028
	Total	**1177**	**2.385**	**.777**	**.022**
Working with Others	Innovative	433	2.536	.797	.038
	Mixed and Traditional	723	2.347	.831	.030
	Total	**1156**	**2.418**	**.824**	**.024**
Likelihood of Becoming an Engineer	Innovative	437	3.345	.627	.030
	Mixed and Traditional	752	3.148	.627	.022
	Total	**1189**	**3.221**	**.634**	**.018**
Responsible for Own Learning	Innovative	437	3.572	.776	.037
	Mixed and Traditional	755	3.525	.824	.030
	Total	**1192**	**3.542**	**.807**	**.023**
Retention in the Engineering Major	Innovative	438	3.550	.848	.040
	Mixed and Traditional	751	3.412	.868	.031
	Total	**1189**	**3.463**	**.863**	**.025**
Graduate School	Innovative	437	3.162	.925	.044
	Mixed and Traditional	755	3.033	.865	.031
	Total	**1192**	**3.080**	**.889**	**.025**
Expected Course Grade	Innovative	438	1.956	1.134	.054
	Mixed and Traditional	743	2.214	1.205	.044
	Total	**1181**	**2.11**	**1.185**	**.034**

on classroom innovation that includes other engineering majors including mechanical engineering, aerospace engineering, and chemical engineering [8, 9, 13].

CONCLUSION

Survey data show that innovative instructional techniques enhanced the instructional environment, which appears strongly related to self-reported student learning outcomes. Most importantly, the innovative sections of ECE 345, irrespective of the instructor, demonstrated statistically significant performance on 11 out of 12 self-assessed student learning outcomes recommended in one form or another in EC2000. Although limited to self-reported data, these results confirm that the time, money, and energy invested in engineering service course reform pay off where it counts—improved student learning outcomes.

In addition, these findings lend support to the claim that alternatives to the lecture or transmission model of instruction may increase learning outcomes. By using alternative methods of teaching, students are more apt to develop critical thinking skills [19], an integral aspect of the engineering design process. Since the engineering education accreditation process examines the amount and quality of engineering design experiences, incorporating teaching methods that enhance these skills can benefit engineering programs in a more general manner beyond individual student outcomes. Using innovative instructional practices including new teaching tools (e.g. course-management software, laboratory videos, and assessment instruments) also affects non-cognitive variables such as the likelihood of becoming an engineer and retention in the engineering major. These outcomes are also vital as the engineering profession seeks to retain and educate future practicing engineers.

RECOMMENDATIONS

One recommendation—perhaps the most challenging—is to institutionalize these reforms to ensure continued improved learning outcomes. To attain this goal, reform efforts will need to be championed by faculty and administrators other than those who taught ECE 345 during the project. Research shows that institutionalizing curricular reforms in higher education settings requires support by the department chair and upper-level administrators, an awareness departmental level culture, and a select number of management skills [20–23] . Supplying academic leaders with information and training in changing management methods is paramount.

Providing opportunities for faculty and teaching assistants to improve teaching strategies to mirror those used in the project (i.e. good pedagogy, use of active and collaborative learning, use and application of design, and attention to classroom climate) is also recommended to improve the quality of learning outcomes in other engineering core courses.

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Additional Resources—For more information about this project please go to http://www.egr.msu.edu/reform. This website provides background information on the research project, project reports, and various assessment tools.

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