Assessing Student Outcomes In A Pedagogically Reformed Engineering Service Course

Dawn M. Zeligman[1], James S. Fairweather[2] and P. David Fisher[3]

Abstract - **Michigan State University (MSU) received an educational research grant from the GE Fund in 1997 for the purpose of seeking ways to reform the early undergraduate engineering learning experience. This educational research project—which is now in its seventh year—has investigated strategies for augmenting introductory core courses with innovative instructional approaches, including cross-disciplinary experiences in teamwork, design, and the use of advanced teaching technologies. Project goals include: improving the quality of the undergraduate student learning experience, encouraging faculty use of innovative instructional techniques, and institutionalizing these reforms. This paper presents a description of one of the course's evolution during the project, methods used to evaluate the course, and the effect of instructional innovations on student learning outcomes.**

Index Terms - Active and collaborative learning, assessing outcomes, course-reform strategies, early undergraduate courses, student learning experiences.

INTRODUCTION

Engineering science core courses represent the initial exposure to engineering for many students. They also form a foundation for degree requirements in each undergraduate engineering major. This educational research project investigated strategies for augmenting two of these introductory core courses with innovative instructional approaches. This paper presents a brief description of the evolution of one service course, *ECE 345: Electronic Instrumentation and Systems*, during the project. We pay particular attention to an important empirical question in undergraduate engineering education— does using active and collaborative instructional approaches improves student learning [1, 2]? Although the literature makes many claims about the effectiveness of student involvement in their own learning, the evidence about these claims is limited [3].

The project was carried out in two phases between 1997 and 2003. The first phase focused on course development and implementation. The second focused on refinement of the courses, evaluation of effectiveness, dissemination, and institutionalization. Additional information about this project can be found at the project website [4]. This website contains background information on this educational research project, as well as research tools, specific outcome data (including additional tables), and analysis.

Electrical and Computer Engineering Service Course

ECE 345: *Electronic Instrumentation and Systems* is a service course open to all undergraduate-engineering majors, except electrical engineering (EE) and computer engineering (CpE) majors. It is currently a three-credit course and has two fifty-minute lectures and one three-hour laboratory period per week. The course is offered fall, spring, and summer semesters and has a total annual enrollment of approximately 400 students. This represents between 10 and 15% of the total student-credit hours (SCH) generated by all ECE-coded courses annually.

ECE 345 serves all departments except Electrical and Computer Engineering. Most departments require *ECE 345* as a "general breadth requirement," although Mechanical Engineering expects *ECE 345* to feed directly into its course on Control Systems. The breadth of service exerts considerable pressure on 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 on-going changes in the field (e.g., analog to digital), few department chairs or their faculty seem willing to remove older material from *ECE 345*.

NEEDS ASSESSMENT AND INITIAL IMPLEMENTATION

The re-development of *ECE 345* proceeded along three parallel paths; interviewing faculty and administrators, benchmarking similar courses at other institutions [5], and gaining an understanding of student perceptions, expectations, and concerns about the course. These data were used to specify course learning objectives, and course content. Revised course content and topics may be viewed on the project website [4].

Interviews were conducted with five stakeholder groups to carry out a needs assessment prior to implementation. These included: (a) students taking or intending to take the courses, (b) faculty and TAs who taught or might teach *ECE 345*, (c) faculty and TAs who taught or might teach courses affected by changes in *ECE 345*, (d) support staff associated with *ECE 345*, (e.g., laboratory assistants), and (e) administrators, whose support is crucial to institutionalizing the instructional innovations (deans and relevant associate/assistant deans,

[1] Dawn M. Zeligman, Research Assistant, Department of Educational Administration, Michigan State University, zeligman@msu.edu
[2] James S. Fairweather, Professor, Department of Educational Administration, Michigan State University, fairwea4@msu.edu
[3] P. David Fisher, Professor Emeritus, Department of Electrical and Computer Engineering, Michigan State University, fisher@egr.msu.edu

department chairs, and program chairs). We extended the interviews into the initial semester of the modified courses to identify common implementation themes. Of these groups, faculty, TAs and administrators articulated redundant opinions and two themes emerged: issues of pedagogy, and faculty opinion on course content and reform.

I. Brief Summary of Pedagogical Issues

Each faculty member and TA developing the new versions of the course showed commitment to student learning and the effectiveness of their instructional methods. While engaging in reform efforts many expressed specific challenges including, (a) difficulty incorporating all traditional material, new material, and innovative instructional approaches into the existing course, (b) the need to "customize" some experiences for students in distinct majors while teaching a large number of students from several majors, (c) the high level of time needed to implement pedagogical innovations, (d) limitations of lecture time and laboratory time due to imposed course credits, and (e) the large variation in student preparation, which made it difficult to prepare the class for an "average" student.

In response to these challenges each faculty participant started developing learning objectives, a substantial improvement over traditional instructional practices in these service courses. In addition, faculty members and TAs took into account content skills such as problem solving and communication, and pedagogy that included group work, active learning strategies, Web-based instruction, and simulations. Also each experimented with various types of instructional approaches and student assessment.

II. Faculty Opinion on Course Content and Reform

Of the five faculty members interviewed, two had previously taught the course, two had never taught the course, and one had taught it for over twenty-five years. They envisioned the course as "supplying knowledge needed for later" in preparing engineers to "pass the licensing examination in order to work as engineers." Although most of the faculty members believed the course to be a sound, solid course with little need for change, the majority of them did not want to teach it.

Some faculty members interviewed believed that newer forms of pedagogy are merely "fluff" and that the pedagogy appropriate in an engineering curriculum was lecture format. In addition, some faculty believed that the only purpose of service courses is for students to memorize material rather than to be able to apply it to solve problems.

As an indication of the difficulties in institutionalizing reforms, few if any of the top teachers in the Department of Electrical and Computer Engineering *(ECE)* would agree to teach *ECE 345* in its innovative format (or in any format). The ECE Chairperson agreed that resolving this problem was every bit as important to institutionalizing reforms in *ECE 345* as changes in course content and instructional approaches. We have demonstrated in other publications [6-8] the importance of the department chairperson in institutionalizing educational reforms within the department.

Finally, faculty rewards appear crucial to long-term faculty interest in innovative teaching. Because course innovations take concerted effort and time, consideration of this investment must be recognized in the promotion and tenure process.

REFORMING ECE 345: ELECTRONIC INSTRUMENTATION AND SYSTEMS

From the assessment interviews mentioned previously learning objectives were established. These objectives affirm that *ECE 345* should (a) convey core knowledge related to electrical engineering fundamentals, (b) transmit core knowledge related to electronic instrumentation and instrumentation systems, including embedded computers, (c) convey essential information related to electrical safety, (d) strengthen math skills through engineering applications, (e) strengthen and expand upon computer skills through engineering applications, (f) enhance problem-solving skills, (g) enhance multidisciplinary teaming skills, including communication skills, and (h) provide some solid ideas and linkages for senior design projects that deploy modern applications of electronic instrumentation and instrumentation systems, including embedded computers.

I. Phase I: Course Assessment and Corrective Actions

We developed a number of assessment instruments tailored to courses like *ECE 345*. These instruments include: Feedback from Lab TAs—Weekly; Feedback from Lab TAs—Final; Feedback from Current Students—Lab Evaluation; Assessment of Student Work in the Lab— Understanding and Lab Skills; Assessment of Student Work in the Lab—Communicating Results to Other Constituents.

The three most significant pieces of useful feedback relate to the training and experience of TAs, the content and sequencing of specific laboratory exercises, and student concern about the grading of laboratory papers.

All TAs assigned to serve as laboratory instructors in *ECE 345* had an undergraduate background in electrical engineering. It became evident during weekly TA meetings with the laboratory supervisor, and from feedback from the students that the TAs had very diverse background, experience, and understanding of the laboratory topics and equipment. Corrective action was taken to improve the quality of the TAs' performance in the *ECE 345* laboratory by changing the process and criteria of TA selection, the training and supervision of TAs throughout the semester, and assessing TA performance in the laboratory.

Assessment outcomes from students taking the course and from the laboratory TAs confirmed that student learning could be improved significantly if the content and sequencing of laboratory experiments were modified. Four specific problems were identified and appropriate changes made in laboratory activities.

First, material introduced one week would in fact be reused in the following week(s) to reinforce application. Second, the learning objectives for both long and short laboratory exercises were evaluated and adjusted so that students would be in the laboratory between two and three hours each week and would have ample time to complete all portions of the experiment for the week. And third, to avoid redundancy and tediousness while still understanding each of the tasks called for in the experiment, each lab group was assigned only a subset to do on their own. They then presented brief oral papers to the others explaining what they did and what there results and conclusions were. This fostered teaming and oral communications.

Although the focus of *ECE 345* was supposed to be on "*Electronic Instrumentation and Systems*," much of the actual laboratory experience focused on the verification of basic electric-circuit concepts. To remedy this situation, individual weekly experiments had learning objectives added to apply these electric-circuit concepts to the measurement and control of physical processes.

II. Phase II: Steps to Continuing Course Improvement

On-going course-reform efforts in *ECE 345* focused on the following primary objectives: (a) focus the course learning objectives on the students' educational needs, (b) improve the quality of the course, and (c) improve the efficiency of course delivery and justify resources needed for the course.

With these in mind we pursued specific tasks each semester to bring about incremental improvements in the course. We first aligned the course learning objectives with course instructional model. Revisions were made to the course plan so topics covered in the lecture aligned with the laboratory portions of the course so laboratory experiences reinforce topics covered in the lecture. Additionally, we revised the laboratory experience so the exercises reflected the course learning objectives. This included reinforcement of topics and skills learned from week to week, and elimination of redundant exercises by using student teams and oral reports.

To address the student concern about the grading of laboratory reports students were given copies of the assessment tools that would be used to evaluate their acquired knowledge and skills. In addition a web-based feedback mechanism was established to encourage an exchange of information between students, faculty, and TAs.

EVALUATING THE EFFECT OF SERVICE COURSE REFORMS ON STUDENT LEARNING

I. Research Questions

Three research questions were developed to evaluate the effect of *ECE 345* curricular reforms on student learning.

- **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 learning outcomes?
- **Research Question 3:** How effective are the GE Fund service course reforms in improving student learning outcomes?

We examined the first question with simple descriptive statistics and cross tabulations. We used a correlation matrix to answer the second question. For the third research question, we compared student learning outcomes from innovative and traditional sections of *ECE 345*, respectively, using one-way and multivariate analyses of variance in combination with Tukey-Kramer HSD post-hoc tests of mean differences. Again, project instruments, detailed findings, tables, and other pertinent information are available at http://www.egr.msu.edu/reform.

II. Survey Instrument

We adopted an instrument developed by Patrick Terenzini and colleagues at Penn State University to assess changes in student learning outcomes in the two target service courses entitled "Student Classroom Experiences." The survey drew on recommendations from ABET (*EC2000*) and several national papers [9].

STUDY VARIABLES

Variable data spanned five broad categories including; course specific information; student demographic data; instructional practice; student self-assessment of learning outcomes; student self-assessed progress on other outcomes.

I. Course-related Design Variables

We used two course-related design variables: The semester and year the course was taught, and the degree of course innovation. For *ECE 345* the degree of course innovation was labeled innovative (using reformed pedagogy and content), mixed (some innovative, some traditional instructional approaches), or traditional.

II. Student Demographics

We gathered data on seven student characteristics: major, gender, race/ethnicity, year in school, hours worked per week, and self-papered Grade Point Average (GPA).

III. Instructional Practices

Four categories of variables addressed specific instructional practices, which when taken together make up what we call Instructional Environment:

- **Good General Pedagogy** was derived from 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, I interact with the TA as part of this course.

- **Evidence of Collaborative or Active Learning** was based on the average score of 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, the instructor encourages students to listen/evaluate/learn from other students.
- **Use of Design and Application** was the average of three items: 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, Race and Ethnicity** was the average scale score of two items: students are treated the same whether white or a minority group member, students are treated the same whether male or female.

IV. Student Self-Assessed Learning Outcomes

Consistent with recommendations in *EC2000,* we created seven constructs from individual items focused on student learning outcomes. Each item that makes up the seven scales starts with the phrase "progress made, because of this course, in your knowledge of" or "ability to." The Learning Outcomes constructs are:

- **Knowledge of the Engineering Profession** is the average of scores on two items: understanding of what engineers do in industry or as faculty, understanding of engineering as a field that often involves non-technical considerations.
- **Engineering Design** is the average score of three items: knowledge and understanding of the language of design in engineering, knowledge and understanding of the process of design in engineering, ability to "do" design.
- **Problem Solving** is the average scale score of five items: 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, use discussion strategies to analyze and solve a problem.
- **Analysis and Assessment of Solution Alternatives** is the average scale score of seven items: 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, and relationships, recognize contradictions/inconsistencies in ideas, data, etc., after evaluating alternatives develop a new alternative that combines the best qualities of previous alternatives, recognize flaws in your own thinking.
- **Application** is the average of two items: apply an abstract concept or idea to a real problem or situation, identify the constraints on the practical application of an idea.
- **Communication Skills** is the average score of three items: clearly describe a problem orally, clearly describe a problem in writing, and explain your ideas to others.
- **Working With Others** is the average scale score of five items: 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, work on collaborative projects as a member of a team.
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V. Student Self-Assessed Progress on Other Outcomes

We added items about the following additional 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.

RESULTS—ANSWERS TO QUESTIONS POSED

What follows are the answers to the three questions posed at the outset of this educational research project.

I. Research Question 1: Who takes ECE 345*?*

We gathered institutional enrollment data and survey return rate data from Spring 1999 to Spring 2003 in *ECE 345*. The total number of students enrolled was 1621, and the total number of respondents was 1236—a 78% return rate. Other demographic and characteristic data included:

- **Declared/Expected Major:** In *ECE 345* expected/ declared varied but the majority represented three fields, mechanical engineering (n=535, 46.6%), chemical engineering (n=234, 20.4%), and engineering arts (n=219, 19.1%)
- **Gender:** Of the total sample of students who responded (n=1189, 96.2%), 29.4% were female and 70.6% male.
- **Race/Ethnicity:** Of the 1138 respondents in *ECE 345*, 63 (5.3%) self identified as Black/African American; 11 (.9%) Mexican-American/Chicano; 7 (.6%) Puerto Rican/Cuban/Hispanic; 1 (.1%) American Indian or Alaskan Native; 998 (84.4%) White/Caucasian; and 28 (2.4%) as Other.

- **Class Year:** Few freshman and sophomores took *ECE 345*. Most students were in their junior (46.6%) or senior (49.5%) year.
- **Highest Degree Expected in Lifetime**: Many *ECE 345* students intend to seek further education. Over sixty-five percent of respondents plan to seek a master's degree, and 11.2% a doctorate.
- **Hours Worked Per Week:** Students in *ECE 345* worked zero to 65 hours a week with the majority (n=453) working between 10-20 hours a week (mean = 11.2, SD = 11.62). Four hundred one students were not employed.
- **Self-Papered Grade Point Average**: Students in *ECE 345* (n=1199) reported a mean GPA of 3.29 (SD=.36).

We did not report findings from three demographic variables because it was apparent that student respondents did not understand the items and/or answered them incorrectly.

II. 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?

Descriptive statistics for four Instructional Environment scales--Good General Pedagogy, Evidence of Collaborative or Active Learning, Use of Design/Application, and Gender/Race/Ethnicity Climate--and 12 *EC2000*-based learning outcomes were correlated. The results strongly suggest that instructional environment is related to student learning outcomes (correlation is significant at the 0.01). For every learning outcome the higher the score on good general pedagogy, active or collaborative instruction, and use of design and application, the higher the student learning outcome. An affable classroom climate for women and minorities was positively related to 4 of the 12 outcomes, and unrelated to the others. They held true across classroom designation (traditional or innovative).

TABLE I

INSTRUCTIONAL ENVIRONMENT BY INSTRUCTIONAL APPROACH

Instructional Environment	Instructional Approach	N	Mean	SD	SE
Good General Pedagogy	Innovative	385	2.722	.5753	.0293
	Mixed & 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 & Traditional	691	2.494	.6166	.0234
	Total	1089	2.543	.6100	.0184
Use of Design and Application	Innovative	417	2.578	.6348	.0310
	Mixed & Traditional	719	2.310	.6984	.0260
	Total	1136	2.408	.6878	.0204
Gender/Race/ Ethnicity Climate	Innovative	408	3.707	.5646	.0279
	Mixed & Traditional	695	3.631	.6620	.0251
	Total	1103	3.659	.6285	.0189

These results strongly suggest that instructional approach "counts." 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 student learning

III. Research Question 3: How effective are the GE Fund service course reforms in improving student learning outcomes?

The results for *ECE 345* are uniformly in favor of the innovative sections of the course (see Table I).

TABLE II

LEARNING OUTCOMES BY INSTRUCTIONAL APPROACH

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

Irrespective of the faculty member teaching the course, when compared with the combination of mixed and traditional sections 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 ($F = 41.7$, $p < .000$, $df = 1, 1134$); gender/race/ethnicity climate ($F = 3.7$, $p < .054$, $df = 1, 1101$). The innovative sections scored significantly higher on 11 out of 12 learning outcomes with the last (responsible for own learning) not significantly different (see Table II). This result is a remarkable achievement given the variation in instructors, students, laboratory assistants, and so forth.

SUMMARY OF THE FINDINGS

The goals of the project were met in part. The goal to improve the quality of the undergraduate student experience was achieved. Survey data show that the quality of the undergraduate student experience in *ECE 345* was improved by using innovative instructional techniques. Several faculty members used innovative instructional techniques in the course, which was the aim of the second goal. The third goal, creating systemic change by institutionalizing these curricula reforms was not achieved. Accomplishing this goal required support and leadership from other constituents (e.g., departmental and college administrators) [10, 11], not merely the faculty teaching the course or researchers involved in the project. This support was not realized and as such course innovations were not institutionalized.

Results strongly suggest that instructional environment is related to student learning outcomes. Correlations of instructional environment and learning outcomes were significant at the 0.01 level. Similarly, descriptive statistics between instructional environment and instructional approach were also significant showing that innovative reforms are positively associated with learning outcomes.

The substantial time, money, and energy invested in engineering service course reform seems to have paid off where it counts the most, improved student learning. The reforms in *ECE 345* were an unqualified success. The innovative sections of the course, irrespective of the instructor, demonstrated statistically significant improvements on 11 out of 12 student learning outcomes recommended in one form or another in *EC2000*.

RECOMMENDATIONS

The recommendations that follow fit into two general categories—i.e., those specific to Michigan State University and those applicable to other institutions. However, even those that tend to focus on MSU appear to have much broader application in academe.

One recommendation, and perhaps the most challenging, is to institutionalize the course reforms to ensure continued improved learning outcomes. To attain this, 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, upper level administrators, an awareness departmental level culture, and a select number of management skills [10-12]. Providing academic leaders with support, information, and training in change 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 ECE courses.

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