First Year Comparative Evaluation of the Texas A&MFreshman Integrated Engineering Program

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Abstract:

The paper documents the first year process and product evaluation of the NSF-sponsored Foundation Coalition (FC) project at Texas A&MUniversity designed to integrate five courses taken by most freshman engineering students: physics, engineering design, calculus, English, and chemistry. In addition to the curriculum integration, the project emphasized cooperative learning, teaming, technology applied to learning, and active learning.

One hundred students of the entering freshman engineering students who were calculus-ready were invited on a first-come, first-served basis to participate; all qualified women and minorities who applied were accepted, and others were accepted on a waiting list in order of application. Entry characteristics indicated that the students did not differ from the freshman class.

FC student achievement in physics and calculus and attitudes toward Coalition engineering goals were assessed both fall and spring. Separate comparison groups were selected fall and spring.

Results indicated that the FC group scored almost identically to the comparison group on the initial testing. For the spring testing the FC group outscored the comparison group statistically on the physics and calculus tests, and all scales of the California Critical Thinking Test except Analysis (no difference). Student attitudes improved for the value of homework, lifelong learning, and decreased in their overall evaluation of engineering. On science, technology, teamwork, communication, and problem-solving there were no significant changes in attitude.

The process evaluation focused on the difficulties and successes in integrating five different subjects and seven faculty members with different curriculum demands, along with changing pedagogy based on cooperative learning, teaming, active (non-lecture oriented) teaching, and technology infusion. Technology infusion was difficult for some faculty to implement due to the demands of both teaching and project development. Changing over from lecture also proved difficult for most faculty, while the integration of content proved feasible, albeit with much work.

Introduction

The College of Engineering at Texas A&MUniversity in 1993 received a five-year award to redesign its undergraduate engineering program, beginning with the freshman year curriculum and moving upward in the curriculum to the sophomore year and then to advanced coursework in various disciplines. A fundamental assumption was made that an integrated freshman curriculum was desirable and attainable. This paper reports initial results of the first cohort of students to complete an integrated freshman curriculum implemented during academic year 1994-95. A major theme for the project was to improve retention of freshman students in engineering, especially female and minority students, who leave engineering after the first year at rates higher than that of white males.

A planning year was devoted to development of the curriculum and pedagogy for the freshman curriculum. The intent of the project was to integrate not only subject matter from physics, calculus, engineering design, English, and chemistry, but to emphasize different pedagogical principles from the traditional lecture-recitation method prevalent in colleges. Literature review and interaction with colleagues both within the university and around the U.S. suggested that a constellation of activities were important to improve student learning. These included four components. First, instruction was based on cooperative learning, which has been linked to improved learning of underprepared students and improved attitude toward school. Second, teaming, which is widely used in industry as a basic model for engineering project development, was emphasized. Third, the infusion of technology early in the student's experience was intended to give students tools to use during their college years and make familiar technology-enhanced learning. Finally, active learning, defined within the project as an orientation toward student interaction, projects, activities, and lessons, was intended to assist learning rather than reliance solely on lecture as the method of knowledge transmission. This did not preclude the use of lecture, although a working assumption was that lectures should be brief (no more than perhaps 10 minutes at a time), with active engagement of students. This mode of instruction was intimately bound with teaming and cooperative learning in that activities were intended to be conducted primarily by established teams of students. Information flow was intended to move between team representatives and instructors in situations when students were not informed as a body. Students were expected to assist each other's understanding both in and out of class.

A special classroom was designed and constructed for the project. Class size was fixed at 50 students per section for the classroom, which was equipped with 25 networked 486 computers. Teams had two computers each; while not assigned to teams, in practice the teams tended to keep the same seats and use the same machines during a semester. All writing, projects, designs, calculations were generally performed on these machines, although separate MAPLE labs were used for calculus instruction with machines dedicated to that purpose. Students had access to MAPLE on their machines, however.

Invitations were sent to the departments of physics, mathematics, English, and chemistry to participate in the project. Nominated faculty were evaluated by project faculty and invited to participate. While some activity took place during the academic year, most planning occurred during the summer of 1994, since faculty time was bought out to develop the curriculum.

Evaluation Design

Samples

During the summer of 1994 all engineering freshman accepted to Texas A&Mwere invited to participate in orientation activities. Most were able to attend, along with their parents in many cases. Students at these orientations were told about the experimental freshman program and invited to apply to the program. All were told that only 100 students would be selected. Women and minorities were especially encouraged to apply. Over 100 students applied from the entering class of 1600, and a waiting list was developed. Student priority led to acceptance of all women (25) and minorities (19). Jointly this was 33 of the 100.

Of the 100, one student never enrolled and another dropped the program early in the semester for reasons unrelated to the project. The remaining 98 completed the semester. Thirteen dropped out at the semester, and 85 completed the spring semester. Seven of these students had failed their first semester calculus, were given a remedial program between semesters, and allowed to begin the second semester course. This gave mixed results, as four dropped the second semester calculus course while failing. The remainder of the paper will focus on the pretest and post-test results of the project, although there is much information of interest on the activities and interactions that occurred during the project.

Comparison groups were formed separately for fall and spring testing from sections of required engineering courses. Students taking the courses were all supposed to be calculus ready, as was true of the FC volunteers, but no specific monitoring took place. It was assumed that most students were taking calculus, as instructors of the sections reported. For the spring testing, no attempt was made to locate and test the same students tested in the fall due to the logistic difficulties. Since the fall testing indicated that the FC students performed identically to the sample of the freshman class tested, it was assumed that the same would be true of the spring testing. Some students from the spring comparison reported that they were not taking physics, although that is a course usually taken by freshman engineering students. The extent of this inequality is unknown and may have contributed to the differences found.

Tests used

A battery of tests was selected based on literature reviews and on project objectives. For physics the Force Concepts Inventory (FCI) [2] and the Mechanics Baseline Test (MBT) [1] were selected. The FCI is intended to assess concept attainment related to linear and angular momentum, while the MBT is a more general physics achievement test in Newtonian mechanics. For calculus a test was developed by the first author with assistance from calculus instructors at several universities. It was oriented toward concepts necessary in understanding calculus without any knowledge of specific differential or integral calculus operators. A matrix of objectives was formed from the topics of the freshman calculus course crossed with three methodological approaches: algebraic, numerical, and geometric. Instructors eliminated items that would not be taught during the freshman year, and a seventeen item exam was constructed. No specific exams were developed for engineering design and chemistry, and common items from exams were used to assess project differences. For English a locally-developed writing exam used to exempt students from freshman English was selected. Results from that exam have not been released by the English Department at the time of the paper’s completion. Finally, the California Critical Thinking Skills Test (CCT) was given to both FC and comparison students at the end of the spring semester to assess possible differences in critical thinking skills. The test presents complex scenarios and asks students to evaluate syllogisms and hypothesized relationships among the variables discussed.

Attitudes were assessed using two different formats. First, an attitude scale was developed to assess the different objectives of the project: to improve students understanding and attitudes toward engineering, science, lifelong learning, technology, teamwork, communication, and problem-solving. Attitude toward homework was also assessed due to previous experience with students’ orientation toward the role of homework in college. This was given only to the FC students. At the end of the year an evaluative survey asking the students to discuss their FC experience was given to students with a return envelope assuring anonymity.

Design

FC and comparison students were assessed on all tests except the CCT at the beginning of the school year, fall 1994. FC students were assessed on attitude and calculus at the end of the first semester. At the end of the year, spring 1995, both FC and comparison students were tested. Different comparison groups were drawn from the freshman engineering class for the fall and spring assessments from required engineering classes. No attempt was made to retest fall testees due to logistics difficulties, although those students will be followed academically for the next several years. The virtually identical performance that an essentially random sample of the freshman class with the FC group on the fall pretests and quite comparable percentages of females (25%) and minorities (13%) provided evidence that the FC group was a reasonably representative sample of the freshman class, although the volunteer effect can never be sorted out. Academically, the FC group was average for its class.

Results

Student achievement

Physics

Initial student scores for the FC and comparison groups on the Force Concepts Inventory were quite similar, almost exactly 50%, and were comparable to scores at another state university, Arizona State. [2]. At the end of the year, the comparison group changed very little (about 1%gain), while the FC group gained about 16%, or almost one standard deviation (SD). Put another way, an FC student at the average on the pretest would score above the 83 %ileon the pretest in the spring. The gain was similar to those reported in [2] for various physics groups, somewhat greater than regular physics and about the same as those reported for the ‘‘Wells method’’ of physics instruction [2]. Results are reported in Table 1. The statistical analyses of both FC-comparison difference on the post-test, and Coalition pretest-posttest gain were significant ($p < .0001$).

The Mechanic Baseline Test results were quite similar to those of the FCI. While the comparison group (38%) slightly outperformed the FC group (37%) on the pretest, the Coalition students gained about 10%(.7 SDs), while the comparison students lost 1%(.14 SDs). Statistical analyses of the FC-comparison difference on post-test and the FC gain were significant ($p < .0001$). Results are given in Table 1. Comparisons with the college groups in [2] indicated FC gains comparable to classes at ASU but well below the end of term scores at Harvard. The latter comparison may be inadequate, because no initial scores were reported for the Harvard group, and they may have started better prepared.

Calculus

The FC (45%) and comparison groups (44%) scored almost identically on the calculus pretest, but the Coalition group gained about 12%(.86 SDs), while the comparison group gained only about 3%(.23 SDs). The difference on post-test between FC and comparison groups was significant at ($p < .001$)

Critical thinking

Only post-tests were given for this test due to testing time constraints. The FC group outperformed the comparison group on the following scales of the test: total score, evaluation, inference, deduction, and inference ($p < .003$ for all tests). The groups did not differ on analysis ($p < .12$). Results are given in Table 1.

Attitude toward Coalition goals

Only FC students were assessed on attitudes toward the eight FC goals; a total score was also computed. Both fall 1994 and spring 1995 assessments were conducted. FC students improved in attitude overall (not significant, and on attitude toward science (not significant), attitude toward homework ($p < .01$), lifelong learning ($p < .01$), and communication (not significant). Their attitude decreased toward engineering ($p < .01$), technology (not significant), teamwork (not significant), and problem-solving (not significant).

Attitude toward the Coalition Program

A survey was given to FC students during the last week of classes in spring 1995 with a return envelope to ensure anonymity. Questions were selected from a list used by several universities to evaluate their program. The 1994-95 freshman FC students named teaming (50%), the availability of and close relationships with the professors (30%), the extensive computer experience (30%), relationships with other students (23%), the integration of content (23%), and the small class size (19%), as the things they liked best about the foundation coalition classes and experiences. Other comments included a belief that they learned more than their classmates in traditional classes, they enjoyed the opportunity the projects gave them, the courses that took the place of other prerequisite courses, and they liked the fact that they could express themselves through the use of +/deltas (a TQM technique to obtain feedback).

Student concerns or dislikes about the program were a general lack of organization and scheduling (32%), the late return of homework (19%), getting tired of the same people, same teams, and same room all year (18%), a feeling that slackers are rewarded and make things difficult for others (14%), and the lack of study time (9%). Other concerns include a) the feeling that the interaction teams did not work due to several professors not meeting with their team, b) a lack of communication between students and faculty and between faculty, c) a feeling that the first couple of weeks were overwhelming, d) heavy class loads, e) too much homework, e) teaming that didn't work, f) more class time required than actual credit given, g) a professor repeatedly arriving late and then holding the class over, h) the program conceived as too idealistic and not realistic, i) too many complaint sessions, j) too much time between classes, k) not enough individual learning, and l) poor matches within teams. A few complaints concerned specific faculty and their teaching habits.

Table 1: Summary of Coalition and Comparison Group Achievement and Attitude Scores

Force Concepts Inventory (scores in percentage form, 29 items)

Group	Pre	Post	Gain
FC	.50	.66	
	.17	.18	
	96	76	
	.52	(note: this group was	.137 $p<.0001$
	.18	the basis for gain	
	76	score analysis)	
Comparison	.50	.512	.11 (ns)
	.18	.21	
	57	40	

When asked how their first year experience compared with that of engineering students not in the FC, responses varied, with some students concluding that their experience provided more than traditional classes did. Comments included: a better understanding of Autocad, Fortran, and Maple, better understanding of the concepts, knew more than other engineering students, worked more but learned more, they were more involved in their classes, and had more access to computers. Some felt that they could not compare the two programs (23%). Others felt bogged down by teaming which took away from their study time, that the FC required more work (9%), and was a harder program, and that FC students spent more time in the lab. Another comment was that while traditional classes were larger and had some poor teachers their schedule was generally easier.

ANOVA on four groups (pre and post, FC and Comparisons)

Group df	Mean Square	F	p
Groups 3	.443	13.58	.0001
error 267	0.33	—	

Tukey comparisons ($p<.05$):
1) FC post > FC pre, Comp pre, Comp post
2) no other significant comparisons

Mechanics Baseline Test (scores in percentage form, 26 items)

Group	Pre	Post	Gain
FC	.38	.47	
	.13	.15	
	92	75	
	.38	.47	.09 $p<0.001$
	70	70	(This group was the basis for gain score analysis)
Comparison	.38	.37	−.01 (ns)
	.15	.16	
	[illegible]	[illegible]	

	55	50	
ANOVA for FC and comparision pre- and post- groups			
Group df	Mean Square	F	p
Groups 3	101.13	7.09	p<.0001
error 268	14.26	—	
Tukey comparisions (p<.05):			
1) FC post > FC pre, Comp pre, Comp post			
2) no other significant comparisons			

Calculus Concepts Test (scores in percentage form, 26 items)			
Group	Pre	Post	Gain
FC	.45	.57	
	.14	.13	
	92	78	
	.49	.57	.08 p<0.001
	78	78	(This group was the basis for gain score analysis)
Comparison	.44	.47	.03 (ns)
	.16	.12	
	56	46	

ANOVA for FC and comparison pre- and post- groups			
Group df	Mean Square	F	p
Groups 3	72.54	13.08	p<.0001
error 276	5.55	—	
Tukey comparisions (p<.05):			
1) FC post > FC pre, Comp pre, Comp post			
2) no other significant comparisons			

California Critical Thinking Skills Test

Group	Scale	score	SD	significance
FC	Total	19.65	4.63	.0001
Comparison		14.33	4.15	
FC	Analysis	5.08	1.96	.42
Comparison		4.86	1.46	
FC	Evaluation	7.41	2.62	.0001
Comparison		4.23	2.54	
FC	Inference	7.16	1.89	.0001
Comparison		5.51	2.61	
FC	Deductive	9.48	2.53	.0046
Comparison		8.05		
FC	Inductive	8.26	2.22	.0001
Comparison		5.44	2.55	

Attitudes (FC group only)

Scale	Pre	Post (Fall)	Post (Spring)	Gain (n = 77 for all 3 testings)
N	99	91	78	
Total mean	145.94	144.67	147.62	1.47 (ns)
SD	9.5	11.8	11.2	
Engineering	22.77	22.29	22.14	−.68 (p<.01)
	1.83	2.46	2.41	
Science	12.14	11.85	12.18	.06 (ns)
	1.55	1.98	1.80	
Homework	12.22	12.67	12.97	.75 (p<.01)
	1.72	1.82	1.58	
Lifelong	18.68	18.97	20.81	2.07 (p<.01)
Learning	2.42	2.58	2.52	
Technology	19.37	19.16	19.29	−0.15 (ns)
	2.66	2.82	2.82	
Teamwork	23.26	22.66	22.56	−.70 (ns)
	3.09	3.32	3.08	
Communication	24.02	23.84	24.32	.32 (ns)
	3.13	2.84	3.08	
Problem-solving	13.20	12.78	13.18	−.21
	2.45	2.43	2.12	

When asked about the teaming experience, reactions were mixed. Most felt it was worthwhile and enjoyed the experience (78%) and noted that they were encouraged to come to class and not procrastinate so they would not let their team down. Some felt that when one team member lost interest it brought down everyone in the team and were not comfortable with the fact that their grade was dependent on others. Others found that they had difficulty reaching team consensus because some refused to compromise, that teaming was taken to an extreme ‘‘we almost moved in with each other’’, and that they possibly did not learn some things as well because they depended on others too much, there was also the concern that slackers were rewarded while those pulling their weight were never rewarded (24%).

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Instructionally, students suggested more homework or quizzes in Engineering and physics, that the math professors become more involved, more practical examples in all classes, chemistry should include acids and bases, FORTRAN should be presented all at once, and projects need to be thought through from the beginning. One student suggested a more classical teaching structure combined with teaming (change is hard). Other ideas were to use more power point presentations, a semester syllabus, more integration of subjects, and better instructing by instructors.

Time students spent per week outside of class varied. Hours per week (number of students reporting that time) were: physics: mean=4.5; calculus, 6.7; chemistry, 5.0; English, 2.3; and engineering design, 6.1. The students felt that their experience would be improved if there was more interaction between the professors and students and between faculty, if the students had been allowed to chose their schedule (early or late), if students schedules were designed so that classes were bunched together, if the program had been more organized, if the homework had more evenly distributed, if the classload was reduced, if the FC system was available on other computers around campus, and if teaming evaluations were done every two weeks. One student suggested not having the program the freshmen year because it ‘‘rewards slackers and slackers should not be at A&Mtheir sophomore year.’’ Others thought that the program was not strict enough and that the testing procedures should be reevaluated, projects should not be due at the end of the semester; coalition student jobs were also suggested.

The most interesting things done by the FC this year included the projects (70%), the variety of software and computers (14%), English class discussions (10%), the time outside of class spent with FC students, and learning in an integrated environment.

Other courses that the FC students took included history (14%), political science, psychology, philosophy, physical education (19%), humanities, and none (24%).

When asked if they would take the FC program if they were beginning college many thought it was a good experience and would (82%), while a few would not (9%) or were undecided (9%).

FC students would recommend the program to a friend starting college (78%), while 14%would not and 9%were undecided.

Formative Evaluation

While a detailed account of the project’s development and implementation would require a paper much longer than the current one, and instead will be written as a technical report to the funding agency, a summary report will help to fill in the otherwise bare bones of the pre-post assessment reported above. Supporting data will necessarily not be presented here.

Curriculum development was accomplished by intense meeting by faculty from the various departments represented, primarily during the summer preceding implementation. After an initial representation of the topics as developed in the traditional curriculum, faculty decided on inclusion or exclusion of topics, and then arranged them concurrently so as to fit sequentially across subject matter (eg., physics, calculus, etc.). Some topics were reintroduced and other eliminated, so that a general flow of topics was achieved. Following that activity, a week by week development of the curriculum was made. Each subject was examined by its content experts to determine what topics from other subjects were necessary for topic development. For example, the introduction of linear momentum and associated laws was determined to depend on the introduction of the derivative in calculus. Concurrently, the introduction of the derivative would foreshadow its use in physics to motivate students and to provide advance organizers for physics learning. Faculty met weekly (or more often) to coordinate their instruction; while the general framework was in place, as a first time experiment, the faculty had to recalibrate continuously to make the integration work. Students received syllabuses and schedules for three-week time periods, which caused some frustration. The students correctly perceived that faculty did not know exactly how the curriculum was fitting together at any particular time point, but given the complexity of fitting five courses together perhaps unfairly castigated faculty for the confusion in the experimental program.

While faculty had attended various workshops on teaming and active learning, those clearly were insufficient to prepare them for the reality of the classroom. Students were placed into teams based on various criteria that research had indicated were appropriate for women and minorities as well as majority males. Early on the problems of teaming surfaced, and faculty grappled with them the rest of the year. Grading practices, student complaints, nonfunctional teams all required faculty attention. Within a few weeks faculty decided they needed student evaluation and created several formats for receiving feedback, including anonymous plus/delta comments on post-its, the development of interaction teams composed of a faculty member and about ten students who were not from the same work teams, and employment of the project evaluators as observers and interviewers of students and faculty. These sources resulted in changes to project activities and orientation; not all student concerns were addressed, but faculty were generally aware of what students were concerned about. Primary concerns included examination procedures, team grading, and faculty teaching; some of this is documented in the student responses given above.

A great deal of time was devoted to the development and grading of tri-weekly examinations, which included both subject-specific and integrated questions. The exams evolved over time as an increasing role of teams was created for answering the integrated exam questions. Faculty spent much time examining test results and deciding on the distribution for grading purposes. Since no normative data were available except for an occasional common item (with traditional course exams when the curricula were common enough to give them).

The development of student projects also required much time and evolved considerably over the year. With the emphasis on team function, both students and faculty were uncertain about how to proceed. Lack of prior experience with such integrated projects was a prime limitation.

The greatest challenge to faculty was the attempt to limit lecturing and shift to a greater use of active teaching with an emphasis on examples, projects, peer instruction, and technology-based learning. This proved to be the most difficult for faculty, and most faculty continued to use lecture as the dominant classroom activity. The lack of external expertise and support to develop the needed activities is probably the greatest cause for the continued use of lecture. Greater familiarity with alternative methods and the year's experience may change this behavior in the future, although the need for external sources remains.

Technological infusion was generally successful, as students learned to use multimedia for communication, computation, numerical and deductive analysis, and instrumentation. Faculty varied considerably in their degree of expertise in using technology as part of their instruction, and in some courses there was little effective use. Again, the need for expert resources was evident; some instruction could have been greatly facilitated by the use of technology-based demonstrations instruction could have been greatly facilitated by the use of technology-based demonstrations examples, and problems. This need was communicated to the project by faculty.

Discussion

Results indicated that the FC group scored almost identically to the comparison group on the initial testing. For the spring testing the FC group outscored the comparison group statistically on the physics and calculus tests, and all scales of the critical thinking test except on the Analysis scale (no difference). Student attitudes improved concerning the value of homework, lifelong learning, and decreased in their overall evaluation of engineering. On science, technology, teamwork, communication, and problem-solving there were no significant changes in attitude.

The process evaluation focused on the difficulties and successes in integrating five different subjects and seven faculty members with different curriculum demands, along with changing pedagogy based on cooperative learning, teaming, active (non-lecture oriented) teaching, and technology infusion. Technology infusion was difficult for some faculty to implement due to the demands of both teaching and project development. Changing over from lecture also proved difficult for most faculty, while the integration of content proved feasible, albeit with much work.

Overall, the evaluation of the Foundation Coalition project was quite positive. Objective indicators indicated greater growth for the students in the Foundation Coalition project than those in the traditional freshman curriculum. The student attitudes were generally positive toward the program and toward engineering, although their attitude was lower than when they entered college. Data are not available to decide if all students exhibit less positive attitudes after their freshman year. Faculty were quite positive about the project and all volunteered to continue for another year. They perceived many benefits from their integrated instruction.

What remains to be seen is if the results will be similar for a second cohort of students, if the project can successfully be scaled up for the much larger groups of students taught at Texas A&M, and if the infusion of new faculty will change the close working relationship developed by the original faculty as well as change the curriculum until it reverts toward traditional instruction. These concerns are true for all innovation in engineering education and will be the focus of future evaluation of the Foundation Coalition Project at Texas A&MUniversity.

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