Collaborative Learning vs. Lecture/Discussion: Students' Reported Learning Gains*

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ABSTRACT

This study examined the extent to which undergraduate engineering courses taught using active and collaborative learning methods differ from traditional lecture and discussion courses in their ability to promote the development of students' engineering design, problem-solving, communication, and group participation skills. Evidence for the study comes from 480 students enrolled in 17 active or collaborative learning courses/sections and six traditional courses/sections at six engineering schools. Results indicate that active or collaborative methods produce both statistically significant and substantially greater gains in student learning than those associated with more traditional instructional methods. These learning advantages remained even when differences in a variety of student pre-course characteristics were controlled.

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I. INTRODUCTION

In recent years, industry and the Accreditation Board for Engineering and Technology (ABET) have increased the pressure on engineering schools to produce graduates who are prepared to engage in unstructured problem solving and to work in groups. Indeed, ABET now requires institutions to demonstrate that their graduates have developed 11 competencies, including the abilities "to design a system, component, or process to meet desired needs," "to function on multidisciplinary teams," and "to communicate effectively."[1] While consensus may exist about what competencies undergraduate engineering students should develop, less clarity and consensus surround the question of how to help students develop these competencies most effectively. The instructional activities taking place in all kinds of college classrooms have recently received increased scrutiny in efforts to enhance the effectiveness of undergraduate teaching. Students' classroom experiences have been shown to have a positive influence on a diverse array of student outcomes, including academic and cognitive development, clarity of educational goals, interpersonal skills, and openness and tolerance towards diversity.[2–5] In general, student learning appears to be enhanced the most when the classroom requires the active involvement and participation of the students on a well-defined and challenging set of interrelated course assignments.[6] Moreover, effective instructional methods stimulate interactions among faculty and students in and outside the classroom environment.[3,7,8]

The relation between students' classroom experiences and learning outcomes for undergraduate engineering students, however, is less well understood than it is in some other disciplines. Dutson, Todd, Magleby, and Sorensen[9] reviewed more than 100 papers and articles relating to engineering design courses. The vast majority of those publications dealt with such issues as course development, structure, characteristics, faculty roles, design project characteristics, industrial involvement, and the composition and activities of student design teams. With respect to how much students had learned, however, they concluded that "The literature is filled with positive comments from students, instructors, and industrial sponsors," but that "The nature of capstone design courses … often leads to a purely subjective evaluation with little or no 'hard evidence' of actual benefits."[9]

Thus, whether active and collaborative approaches are more, less, or about-equally as effective as less learner-active methods in teaching design to engineering undergraduates remains very much an open question. As Dutson, *et al.*[9] make clear, design has been (and still is) taught using a variety of approaches. The argument underlying recent calls for reforms in engineering education, however, is that traditional methods of teaching "design" have not produced graduates with the kinds of skills they need to be effective engineers (e.g., working in teams; applying scientific and engineering theory and principles; solving unstructured, practical problems, and communicating with others). The widespread (and reasonable) *belief* is that active and collaborative instructional approaches will be more effective than conventional instructional methods (i.e., lectures/discussions) in helping students develop these vital engineering skills. As noted, however, that belief has not been widely examined nor clearly established empirically in engineering education. This study put that belief to the test.

II. Methods

The study was done on the campuses of the colleges of engineering that make up the Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL). With support from the National Science Foundation, ECSEL has sought (among its several goals) to enhance undergraduate engineering students' learning through the introduction and diffusion throughout the undergraduate engineering curriculum of active and collaborative approaches to teaching design.

To address the central question ("Are active and collaborative approaches to teaching engineering design any more effective than conventional approaches?"), the Center for the Study of Higher Education at the Pennsylvania State University developed the "Classroom Activities and Outcomes Survey." This four-page, pencil-and-paper, multiple-choice questionnaire (distributed and completed during a class session) gathers information in three areas: 1) students' personal and academic backgrounds and demographic characteristics; 2) the instructional characteristics of the course in which they were enrolled when completing the questionnaire, and 3) the extent to which students believed they had made progress in a variety of learning and skill development areas *as a result of taking that particular course*. (A revised version of the instrument is available from the lead author.)

The instrument was administered in selected courses offered during the spring 1997 semester on six of the seven ECSEL campuses. Because this was a pilot test of the instrument, participating courses and students were not randomly selected. The local ECSEL evaluator on each campus was asked to identify at least one "ECSEL" course (in which design was being taught using active and collaborative learning techniques) and one "non-ECSEL" course (for comparative purposes), wherein traditional lecture and discussion techniques were the primary instructional method. Local evaluators were asked to select non-ECSEL courses that were as close as feasible to the ECSEL courses in their educational goals.

A total of 17 ECSEL courses/sections and six non-ECSEL courses/sections were surveyed. Of the ECSEL courses, eight were engineering science-type courses. The remaining nine came from such content domains as structures and mechanics of materials, automatic controls, product engineering and manufacturing, design, physics, and thermodynamics. Eleven of these ECSEL courses were offered at the 100- or 200-level, and 6 were 300- or 400-level courses. The non-ECSEL courses were in statistics (2), mechanics and materials, electrical circuits, and a senior design project course not involving group work. The content of one non-ECSEL course was unspecified. Two of the six were lower-division courses, and three were offered at the upper-division level (the level of one course was unspecified).

A total of 480 students on the six campuses completed usable assessment forms. Of the 480 students, 339 (71%) were enrolled in an ECSEL course while 141 (29%) were in non-ECSEL courses. Because of the non-random nature of the data collection, 48 percent of the students were enrolled at the University of Washington, 22 percent at the University of Maryland, 19 percent at City College of New York (CCNY), and 11 percent at Howard University, Morgan State University, or The Pennsylvania State University. Of the 339 ECSEL students, 53 percent came from the University of Washington, 20 percent from Maryland, and 15 percent from CCNY; 12 percent came from the aggregate of Howard, Morgan State, and Penn State courses and students. Tests indicate that the students in the two groups did not differ at statistically significant levels with respect to gender, race/ethnicity, high school grades, degree aspirations, class year, or parents' education. Non-ECSEL students, however, reported somewhat (but statistically significantly) higher SAT scores.

III. Results

A. Course Characteristics

One section of the Classroom Activities and Outcomes Survey asks students to indicate how often they (or their instructor) engaged in each of 24 instructional activities. The scale ranges from 1 to 4, where 1 = "never," 2 = "occasionally," 3 = "often," and 4 = "very often/almost always." ("Not applicable" responses were excluded in the calculation of group means and subsequent statistical tests.) The items comprising this section were drawn from the research literature on effective instructional approaches and activities.

Table 1 reports the group means for the 18 (of 24) items on which the groups differed at statistically significant levels (based on t-tests). For interpretative ease, the items have been grouped in four clusters: collaborative (or group) learning activities, problem-solving activities, feedback from instructors and peers, and interactions with faculty members and other students. As can be seen in Table 1, the ECSEL-course students' means were higher than those of their non-ECSEL peers on 17 of the 18 items. Only on the item dealing with the extent to which students in the course were treated similarly regardless of their gender did non-ECSEL students rate their course significantly higher than the ECSEL-course students. A similar, but statistically non-significant ($p < .07$) relation, was suggested in a similar item regarding the equality of treatment regardless of students' race/ethnicity. One possible explanation for the "unequal treatment" findings is that they are a function of the instructional approaches used in the two different settings. In conventional (usually lecture and discussion) courses, instructors engage students in an "I pitch, you catch" relationship that affords students few opportunities to interact with the instructor or with their peers. ECSEL courses, on the other hand, with their emphasis on group work and active and collaborative learning, provide more occasions for students to interact with one another and to encounter and engage other students who may have different ideas, personalities, cultural backgrounds, and value sets. These more frequent opportunities for interaction, of course, also present more frequent opportunities

Course Characteristics	Means[a] ECSEL (n=291-331)	Means[a] Non-ECSEL (n=122-139)	Effect Size[b]
Collaborative Learning			
I work cooperatively with other students on course assignments.	3.21	2.50	+25
Students teach and learn from each other.	2.96	2.60	+14
There are opportunities to work in groups.	3.51	2.20	+39
I discuss ideas with my classmates (either as individuals or in a group).	3.14	2.51	+23
We do things requiring students to be active participants in the teaching/learning process.	2.92	1.91	+35
Instructor guides students’ learning activities rather than lecturing or demonstrating course material.	2.74	1.99	+28
Instructor encourages students to listen, to evaluate, and to learn from the ideas of others.	2.98	2.11	+31
Instructor emphasizes design process and activities.	3.04	2.39	+26
Problem-solving Activities			
I'm encouraged to show how a particular course concept can be applied to an actual problem or situation.	3.04	2.79*	+10
I have opportunities to practice the skills I'm learning in the course.	2.82	2.40	+16
Feedback			
I get feedback on work/ideas from classmates.	2.83	2.20	+23
Instructor gives **frequent** feedback on my work.	2.70	2.25	+18
Instructor gives **detailed** feedback on my work.	2.51	2.13	+15
Interaction with Faculty/Peers			
I'm encouraged to challenge the instructor's or other student's ideas.	2.68	2.34	+14
I interact with instructor as part of this course.	2.71	2.01	+26
I interact with this instructor outside of class.	1.84	1.51	+15
I interact with other students in this course outside of class.	2.96	2.70*	+10
Students are treated the same, whether male or female.	3.63	3.75*	-8

[a] All means differ at $p<.001$ with three exceptions (asterisked). The first two differ at $p<.01$, the third at $p<.05$.
[b] Difference in means represented in percentile-point units. See Note 1 for an explanation of how effect sizes are calculated.

Table 1. Course characteristics with statistically-significant group differences.

for conflict (as well as developing gender and racial/ethnic tolerance and respect) as students encounter people and ideas different from their own.

The "Effect Size" column in table 1 offers information on the magnitudes of the differences between ECSEL and non-ECSEL course groups in the frequency with which they reported that a particular classroom activity or condition occurred. The effect size* is interpretable as the difference in percentile points between the mean of the ECSEL group and the mean of the non-ECSEL group (with this group's mean set at the 50th percentile). Values close to zero indicate no difference in the frequency with which a classroom activity or condition is reported, while effect sizes greater than zero indicate the number of percentile points the ECSEL group is above (+) or below (−) the non-ECSEL group. For example, if the non-ECSEL group mean on the first item (the frequency with which students report "work[ing] cooperatively with other students on course assignments") constitutes the 50th percentile, the average frequency with which ECSEL group students report that same activity is 25 percentile points higher, or at the 75th percentile. On nine of the 18 items, the ECSEL group mean is 20 or more percentile points higher than that of the non-ECSEL group.

The information in Table 1 constitutes strong evidence that what happens in ECSEL-courses is systematically and significantly (statistically) different from the activities reported by students in non-ECSEL courses. Those activities, moreover, have been shown by previous research to be related to greater learning gains among students.[3] Compared to their non-ECSEL course peers, ECSEL-course students consistently reported more opportunities to work in groups, a greater course emphasis on the design process and activities, more active involvement in their own learning, more course-related (and out-of-class) interactions with other students in the course, more in- and out-of-class interaction with faculty members, more frequent and more detailed feedback on their performance from instructors and peers, and more encouragement from faculty members to challenge the ideas of instructors and other students.

*Effect sizes are calculated by taking the ECSEL group mean minus the non-ECSEL group mean divided by the non-ECSEL group standard deviation. The resulting z-score is then used with a table of the areas under the normal curve to estimate the percentile-point difference between the group means with the non-ECSEL group mean defining the 50th percentile.

B. Learning Outcomes

The Classroom Activities and Outcomes Survey instrument also asks students to indicate the progress they believe they had made in each of 27 areas *as a consequence of the course* they were taking and for which the survey form was being completed. (To ensure that students clearly understood that their responses throughout the questionnaire were to be specific to the course in question, the phrases "in this course," "as a result of this course," or "because of this course" appear 16 times in the survey form. Half of those phrases are printed in bold face.) Progress is reported on a 1-to-4 scale, where 1 = "none," 2 = "slight," 3 = "moderate," and 4 = "a great deal." The items were drawn primarily (but not exclusively) from a series of Delphi studies by Jones and her colleagues[10,11] intended to develop consensus among faculty members, research specialists, academic administrators, and employers on definitions and components of "critical thinking," "problem solving," and "communications." Items were selected from this study, or developed specifically, to reflect as closely as possible seven of the 11 learning outcomes articulated in ABET's *Engineering Criteria 2000.* The ABET criteria dealing with development of professional and ethical responsibilities (f), understanding engineering solutions in a global context (h), life-long learning (i), and a knowledge of contemporary issues (j) were considered more reasonable expectations as programmatic—rather than single-course—outcomes.

A principal components factor analysis of the 27 items (using an orthogonal rotation) was carried out to facilitate interpretation of the results from this portion of the study. Factor analysis is a statistical procedure for identifying items that appear to be measuring a common, underlying construct or "factor." Items common to a factor can then be combined into a "scale" and used in subsequent analyses. Scales have the dual advantages of being fewer in number (and, therefore, easier to comprehend) and more reliable representations of the underlying construct or factor being measured.

Table 2 reports the ECSEL and non-ECSEL group means for each of the four scales (in bold face) derived from the factor analysis. The means for the items comprising each scale are reported under the scale heading. Each scale's internal consistency (alpha)

Course-related gains in:	Means[a] ECSEL (n=294-321)	Means[a] Non-ECSEL (n=129-138)	Effect Size[b]
Design Skills (Alpha=.87)	**2.84**	**2.38**	**+23**
Understanding of what engineers "do" in industry or as faculty.	2.91	2.62	+12
Understanding of engineering as a field that often involves non-technical considerations (e.g., economic, political, ethical, and/or social issues).	2.58	1.88	+27
Knowledge and understanding of the **language** of design in engineering.	2.81	2.66	n.s.
Knowledge and understanding of the **process** of design in engineering.	3.04	2.55	+19
Your ability to "do" design.	2.85	2.23	+23
Problem-solving Skills (Alpha=.86)	**2.89**	**2.83**	**n.s.**
Your ability to identify what information is needed to solve a problem.	3.05	3.05	n.s.
Your ability to apply an abstract concept or idea to a real problem or situation.	2.90	2.58	+14
Your ability to divide problems into manageable components.	2.88	3.15	-14
Your ability to develop several methods which might be used to solve a problem.	2.84	2.77	n.s.
Your ability to use established criteria to evaluate and prioritize solutions.	2.78	2.63	n.s.
Communication Skills (Alpha=.86)	**2.84**	**2.57**	**+11***
Your ability to clearly describe a problem orally.	2.85	2.51	+13
Your ability to clearly describe a problem in writing.	2.83	2.64	n.s.
Group Skills (Alpha=.93)	**2.96**	**2.09**	**+34**
Develop ways to resolve conflict and reach agreement in a group.	2.87	1.84	+36
Be aware of feelings of other members of the group.	2.85	1.88	+32
Listen to the ideas of others with an open mind.			
Work on collaborative projects as a team member.	3.11	2.22	+27
Organize information into categories, distinctions, or frameworks that will aid comprehension.	3.22	1.91	+37
Ask probing questions that clarify facts, concepts, or relationships.	2.95	2.29	+24
After evaluating the alternatives generated, to develop a new alternative that combines the best	2.86	2.25	+22
qualities and avoids the disadvantages of the previous alternatives.	2.83	2.16	+26

Table 2. Course-related differences in learning outcomes.

Course-related gains in:	Means[a] ECSEL (n=294-321)	Non-ECSEL (n=129-138)	Effect Size[b]
Other, Unscaled[c] Items			
Your ability to evaluate arguments and evidence so that the strengths and weaknesses of competing alternatives can be judged.	2.87	2.35	+21
Your ability to explain your ideas to others.	3.02	2.53	+18
Your ability to be patient and tolerate the ideas or solutions proposed by others.	3.04	2.51	+19
Your ability to understand that a problem may have multiple solutions.	3.11	2.86	+11*
Your ability to use discussion strategies to analyze and solve a problem.	3.03	2.55	+18
Your ability to recognize contradictions or inconsistencies in ideas, data, images, etc.	2.89	2.32	+22
Your ability to identify the constraints on the practical application of an idea.	2.93	2.29	+24
Your ability to recognize flaws in your own thinking.	2.94	2.64	+12

[a]Difference in means are statistically significant at p<.001 UNLESS: a) an effect size is denoted as non-significant [n.s.], or b) the effect size has an asterisk, in which case the difference in the means is statistically significant at p<.01.
[b]Difference in means represented in percentile-point units. See Note 1 for an explanation of how effect sizes are calculated.
[c]Loaded at .40 on two or more factors and, therefore, were excluded from the scales because of the ambiguities of interpretation.

Table 2. (Continued)

reliability is also reported. That index reflects the extent to which the items comprising a scale are measuring the same thing (i.e., are consistent with one another). An alpha coefficient can range from .00 (indicating no consistency whatever and the presence of a great deal of measurement error or "noise") to 1.0 (reflecting perfect consistency: respondents answering one item in a certain way consistently answer similar items in the same way). A scale with an alpha of .70 or greater is generally considered psychometrically sound.

As can be seen in Table 2, the factor analysis produced four factors, labeled to reflect their general content (the underlying "factor"): "Design Skills," "Problem-solving Skills," "Communications Skills," and "Group Skills." The four factors together accounted for 66 percent of the total variance in the items (an unusually high percentage, indicating that relatively little information is lost in using the factor-based scales rather than the individual items for subsequent analyses). The factors were also uncommonly clean; very few items loaded at or above .40 on multiple factors, which would indicate an unclear item. The internal consistency reliabilities of the four scales range from .87 to .93 and are well above the conventional standard for measurement adequacy.

Examination (using t-tests) of the significance of the differences in group means on each of the scales (and their component items) indicates that ECSEL students reported significantly greater gains than non-ECSEL course students in developing their design, communications, and group skills. More impressive is the fact that these differences are not only statistically significant, but also substantively large. The "Effect Size" figures indicate (in percentile-point units) the magnitude of the differences in reported gains. As can be seen in Table 2, ECSEL students (compared to their non-ECSEL peers) reported gains that ranged from 11 percentile points higher in developing their communications skills, to a 23 percentile-point advantage in building their design skills, to a 34 percentile-point advantage in developing their group skills.

On only the Problem-Solving Skills scale did the two group not differ at a statistically significant level. This finding may be attributable, at least in part, to the items that made up the scale. It is possible (perhaps even likely) that the scale's items did not differentiate sufficiently in respondents' minds between the *structured, textbook, mathematical, or computational* problems (having a single, known solution) common to most engineering courses, and the *unstructured, open-ended, and practical* problems students confronted in ECSEL courses (i.e., problems for which multiple solutions are possible). Simply put, "problem" may have had different meanings for the two groups. It may be worth noting (although we do so cautiously) that: 1) while the differences in group means on this scale are not statistically significant, they are in the hypothesized direction favoring the ECSEL classroom experiences; 2) on three of the five items comprising the scale (the second, fourth, and fifth), the ECSEL group means are higher than those of the non-ECSEL group (only the difference on the second item, however, is statistically significant), and 3) the content of all 3 of those items tends to be more relevant to solving unstructured, rather than structured, problems. (The items on this scale were subsequently revised so as to refer to solving "an unstructured problem (that is, one for which no single, 'right' answer exists)." Analyses of over 1,250 student responses to the revised items and scale indicate a statistically significant and substantial relationship between exposure to active and collaborative instructional methods and reported gains in problem-solving skills as redefined.[12,13]

The bottom of Table 2 reports the group means on eight additional outcome items that the factor analysis suggested contributed to more than one factor. Consequently, these items were excluded from the scales. Nonetheless, because we believe the group differences are revealing, the items and group means are reported individually. In all cases, the ECSEL group mean is higher than that of the non-ECSEL group, with effect size advantages ranging from 11 to 26 percentile-points.

C. Multivariate Analyses of Learning Outcomes

Because students self-selected themselves into the ECSEL and non-ECSEL courses, it is possible that the differences in group scale and item means described above *may* be due to pre-course differences among the students. Students with certain ability or motivational levels (or other characteristics) may have been more likely to enroll in one kind of course than the other. To explore this possibility, three multiple regression analyses were conducted (one each for the design, communications, and group skills scales) to control for pre-course differences among students. This analytical procedure permits evaluation of whether (and to what extent) any differences in the two groups' reported gains are attributable to their instructional experiences *above and beyond* any differences in student characteristics. In each of the three regressions, gender, race/ethnicity, parents' education, high school achievement (GPA), academic ability (SAT verbal and math scores), degree aspirations, and class year (lower vs. upper division) were controlled.

In each regression, group membership (i.e., taking an ECSEL vs. a non-ECSEL course) was significantly related to reported gains net of student pre-course differences. Thus, the greater gains in their design, communication, and group skills reported by ECSEL students persist even after a number of potentially confounding pre-course differences are taken into account. Indeed, the differences in gains on each scale were influenced substantially more by type of course taken than by any of the pre-course student characteristics. Such results lend credence to a claim that the active and collaborative pedagogical practices used in the ECSEL courses had a positive and substantial educational influence on student learning in a variety of outcome areas identified by ABET and industry as important for the development of future engineers.

D. Limitations

Like any piece of social science research, the findings in this study are subject to several constraints. First, the study relies on students' self-reports of cognitive and psychosocial changes rather than on more objective measures (e.g., standardized tests or absolute demonstrations of learning gains). Recent research suggests, however, that self-report measures of learning are appropriate and valid indicators of gains in cognitive skills. Pike[14] found self-reported measures of educational gains to be as valid as objective measures to the extent that the self-report measures reflect the content of the learning outcome under consideration. As noted earlier, the self-report items reflecting the learning outcomes studied in this research came primarily (albeit not exclusively) from a national study of the beliefs of faculty members, researchers, administrators, and employers about what component abilities make up those skills.[10,11] Similarly, Anaya,[15] after examining a representative sample of students who took the Graduate Record Examinations in 1989, concluded that self-reported measures of gains in cognitive skills are valid proxies of cognitive skills as measured by the verbal and math components of the GRE. Moreover, while standardized measures have some advantages over self-reports, they also come with limitations of their own for classroom use, including availability, length, cost, and relevance to specific courses. The self-report instrument used in this study was designed specifically to gather course-level information relevant to the ABET criteria and to be easy and inexpensive to use. One must, nonetheless, acknowledge the trade-offs being made.

Second, while local evaluators on the ECSEL campuses were asked to select non-ECSEL courses that were similar to the ECSEL courses in their educational goals (i.e., teaching design skills), no claims can be made about how effectively this goal was achieved. Thus, differences in the learning gains students reported in ECSEL and non-ECSEL courses may be attributable to differences in course objectives. For example, the non-ECSEL courses may not have had development of problem-solving, group, and communications skills as course objectives. The fact that three of the six non-ECSEL courses were upper-division offerings (including one specifically entitled "Senior Design Project"), as well as the substantial effect sizes, tends to moderate this threat to the study's internal validity. The threat cannot, however, be ignored. It is nonetheless worth bearing in mind that the learning outcomes under study have been identified by ABET (and informally by industry representatives) as important skills for engineering graduates, whatever the offering department or content of the courses taken.

Third, the study does not take into account professors' instructional skills and attitudes toward teaching undergraduates. Non-ECSEL course instructors may have been less effective teachers regardless of the instructional methods used. Had ECSEL course instructors used traditional teaching methods, they might still produce reported learning gains greater than those of less skilled instructors. While the data to evaluate this potential threat to the study's internal validity are unavailable, the magnitudes of the effect sizes we observed are *so* great—ranging from 11 to 34 percentile points—that it seems unlikely that controlling instructor skills and attitudes would equalize the effects of the instructional methods used.

Finally, the fact that the results reported here are based on a non-random sample of students and courses at ECSEL institutions limits somewhat the generalizability of both findings and the conclusions to which they lead. It is worth noting, however, that the data for this study come from nearly 500 students in 23 courses/sections offered at all levels of instruction in multiple engineering departments on six quite different campuses. Such heterogeneity tends to militate against the possibility that the relations we observed were really anomalies due to non-random sampling.

V. Conclusions and Implications

Calls for reform in undergraduate engineering claim that graduates lack the necessary training and experience in solving unstructured problems, working in groups, and communicating effectively with engineers and others. ABET has listed eleven program outcomes that will form the basis for reaccredidation reviews. Implicit in these calls for reform and in ABET's *Engineering Criteria 2000*[1] is the belief that engineering courses employing more active and collaborative approaches to teaching will be more effective than conventional, lecture-based courses in promoting students' engineering skills.

While a growing body of research indicates that active and collaborative approaches to instruction may well be more effective than conventional lecture/discussion methods, it remains an empirically open question whether that relation holds in teaching engineering design. This study sought to evaluate whether active and collaborative teaching methods were, indeed, more effective than conventional instructional approaches in promoting students' design skills and, if so, to what degree. Results indicated that "ECSEL" students (i.e., those taking courses taught using active and collaborative approaches to teaching design) reported statistically significant advantages in a variety of learning outcome areas when compared with "non-ECSEL" students, who were enrolled in conventionally taught courses. ECSEL students reported learning advantages in three areas: design skills, communication skills, and group skills. The advantages enjoyed by ECSEL students were both statistically significant and substantial. On average, ECSEL students reported learning gains of 11–34 percentile points higher than those of their non-ECSEL peers in communication skills (11 points), design skills (23 points), and group skills (34 points). These reported learning gains, moreover, persisted even when controlling for relevant pre-course student characteristics (e.g., gender, race/ethnicity, parents' education, high school grades, SAT scores, degree aspirations, and class year). While analyses also suggested a positive link between active and collaborative approaches and reported gains in problem-solving, that relation was not statistically significant. Subsequent analyses,[12,13] however, support the presence of such a relation.

These results have implications for accreditation, classroom management, curriculum, faculty development, and the recruitment and retention of under-represented groups in engineering. For example, an emphasis on active and collaborative learning through the early and pervasive use of design in the engineering curriculum is consistent with the goals of the *ABET 2000 Criteria*. This pedagogical strategy, as shown in this study, promotes effective instruction. Student gains in communication skills, design skills, and group participation skills—all endorsed by ABET—appear to be more likely to occur when the classroom experience itself stresses collaborative and active learning.

Structuring classroom activities that promote gains in communication, design, and group skills are by their very nature complex. Developing exercises and assignments that call for design-based learning, coupled with the emphasis on constant feedback, will require specialized abilities and knowledge that will, in turn, require training or substantial experience for most faculty members. Strong commitment to faculty development will be needed on the part of engineering departments and colleges to facilitate the constant upgrading of critical teaching skills and techniques.

The effort required in designing courses and curricula that foster cognitive skill development through active and collaborative learning techniques raises another critical administrative consideration: the weight given to course development and teaching in salary, promotion, and tenure decisions. An assistant professor or associate professor confronting the competing demands for teaching, research, and service is unlikely to see much benefit in learning-by-design activities and in promoting collaborative learning if these activities are neglected when significant personnel decisions are made. Interviews with both ECSEL and non-ECSEL faculty point to this consideration as a major deterrent to their involvement in teaching design-based courses. If engineering colleges do, indeed, value gains in students' design, problem-solving, group, and communication skills, then the colleges and their host institutions must examine the extent to which their faculty reward criteria, standards, and policies provide adequate incentives to encourage faculty to pursue these instructional goals.

The findings of this study provide empirical support for beliefs about the greater effectiveness of active and collaborative learning compared with more traditional approaches to developing students engineering skills. While adoption of these learner-active approaches are likely to require non-trivial changes in current instructional philosophies, faculty habits, and faculty reward systems, the evidence reported here suggests that efforts to make those changes are likely to be educationally worthwhile.

Notes

1. Effect sizes are calculated by taking the ECSEL group mean minus the non-ECSEL group mean divided by the non-ECSEL group standard deviation. The resulting z-score is then used with a table of the areas under the normal curve to estimate the percentile-point difference between the group means with the non-ECSEL group mean defining the 50th percentile.

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