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AUTHOR	Springer, Leonard
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ABSTRACT

The central research question in this study was whether structured active learning affects the abilities of science and engineering undergraduates to relate abstract concepts and realistic applications more than a relatively traditional instructional method. More specifically, the research was designed to determine whether differences in the learning outcome were apparent to faculty representing a variety of disciplines as well as to the students who participated in the course. The effects of structured active learning on the measured outcome were compared between men and women. The results suggest that students who participated in structured active learning perceived a greater ability to connect abstract concepts and real-world applications than students who participated in a relatively traditional instruction program. Faculty from a broad range of disciplines also perceived that students who participated in structured active learning were more competent than their counterparts in the traditional program, particularly in comprehending the larger context surrounding a problem and understanding the relationship between theory and practice during the problem-solving process. The positive effect of structured active learning on students' abilities to connect concepts and applications extended to both men and women. (PVD)

RELATING CONCEPTS AND APPLICATIONS THROUGH STRUCTURED ACTIVE LEARNING

Leonard Springer
Wisconsin Center for Education Research
University of Wisconsin-Madison
796 Educational Sciences
1025 West Johnson Street
Madison, WI 53706
Lspringe@facstaff.wisc.edu

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RELATING CONCEPTS AND APPLICATIONS THROUGH STRUCTURED ACTIVE LEARNING

Background

American academic, industrial, and political leaders increasingly suggest that educators focus on the need for scientists and engineers to apply their knowledge to real-world problems (Executive Office of the President, 1994). Employers commonly seek graduates of science and engineering programs who are able "to work in groups and integrate science and technology to meet the needs of industry and other sectors" (Good & Lane, 1994). Yet leaders in business and industry consistently note that many college graduates lack the ability to work together on complex problems. Consequently, employers frequently have to provide in-house or on-the-job training in small group interaction (Cuseo, 1991).

Addressing this problem, a National Science Foundation (1996) report concludes that teaching and learning methods in undergraduate science, mathematics, and engineering courses have not kept pace with rapid changes in the nature of work and technology worldwide. Undergraduates in science and engineering commonly complain that traditional instruction does not prepare them adequately to relate abstract concepts and realistic applications (Rubinstein, 1994). Grants for reforms in science, mathematics, engineering, and technology education have stimulated the adoption of a broad range of teaching and learning methods designed to address the problem. Goals of these innovations include structuring classroom experiences to be more similar to actual career situations. Students generally are given greater opportunities to learn from one another and to work in small groups on authentic problems.

These small-group teaching and learning innovations have been identified by a number of labels including cooperative learning, collaborative learning, active learning, and problem-based learning. Of these methods, cooperative learning has been accompanied by the most educational research. Several meta-analyses (e.g., Bak, 1992; Johnson & Johnson, 1989; Qin et al., 1995;

Slavin, 1995), encompassing more than 700 primary studies in total, document the impact of various forms of cooperative learning on student outcomes including greater academic achievement (Bak, 1992; Johnson & Johnson, 1989; Qin et al., 1995; Slavin, 1995), higher problem-solving ability (Qin et al., 1995), more supportive relationships with peers (Johnson & Johnson, 1989; Slavin, 1995), and greater self-esteem (Johnson & Johnson, 1989; Slavin, 1995). Slavin's (1995) analysis asserts that cooperative learning enhances the ability of students to apply their knowledge to real-world situations while Bak's (1992) indicates that the effects of cooperative learning tend to be greater in the sciences. These meta-analyses focus almost exclusively on students in elementary and secondary schools, however.

The question of whether small-group learning is also effective in postsecondary education has precipitated a growing number of reviews of the research literature in this area. Meta-analyses have documented the impact of active (e.g., Johnson et al., 1991a, 1991b), cooperative (e.g., Springer et al., 1997), and problem-based (e.g., Vernon & Blake, 1993) learning on college student outcomes including greater academic achievement in science and mathematics (Springer et al., 1997), increased persistence to degree (e.g., Johnson et al., 1991a, 1991b), more supportive relationships with peers (e.g., Johnson et al., 1991a, 1991b), greater self-esteem (e.g., Johnson, et al. 1991a, 1991b), and more favorable attitudes toward the material (e.g., Vernon & Blake, 1993). Primary studies relevant to engineering education (e.g., Felder & Brent, 1994; Jones & Brickner, 1996; Mourtos, 1997), although fewer in number than in the sciences and mathematics, tend to corroborate these results.

In general, however, primary studies of teaching and learning in undergraduate science and engineering have been limited methodologically. Qualitative research that contrasts the experiences of students and faculty in traditional courses with their counterparts involved in educational reform initiatives have frequently been characterized as anecdotal, prompting questions of validity. Quantitative studies generally focus on relatively narrow student outcomes (such as persistence, attitudes, or grades), and are limited in their ability to represent how participants actually experience the teaching and learning processes occurring inside and outside the classroom. In addition, differences due to instructional methods generally have not been separated from differences due to characteristics of the students or instructors. Moreover, studies generally do not combine the variety of assessment methods--such as observations, interviews, and survey analyses--necessary to address these complex questions. Furthermore, no known studies address the question of whether various innovations in undergraduate science and engineering education increase the ability of students to relate concepts and application more than traditional instructional methods.

Purpose

The central research question is whether structured active learning affects the abilities of science and engineering undergraduates to relate abstract concepts and realistic applications more than a relatively traditional instructional method. More specifically, I sought to determine whether differences in the learning outcome were apparent to faculty representing a variety of disciplines as well as to the students who participated in the course. I also questioned whether the effects of structured active learning on the measured outcome differed for men and women.

Perspective

Structured active learning is based on the premise that students become more involved in learning when they are engaged in creative work that is meaningful to them. A goal that follows from this premise is to facilitate the ability of students to relate abstract concepts and various realistic applications. An assumption underlying the goal is that students perceive greater meaning in coursework that links theory and practice. The overarching strategy for achieving the instructional goal is to encourage students to learn from one another while providing the structure and support necessary for them to address authentic problems.

Method

I analyzed data collected by researchers affiliated with the LEAD Center[1] to address the research questions. The data were collected based on a quasi-experimental design, with one experimental and one control group. The population for the study was students enrolled in two sections of a second-semester course in analytical chemistry intended for first-year science and engineering majors at a Research I university in the Midwest. During spring 1995, 180 (95 percent) students participated in the study. The sample was comprised of 170 (94 percent) first-year students, 58 (32 percent) engineering majors, 67 (37 percent) women, and 3 (2 percent) underrepresented racial or ethnic minorities. Of the sampled students, 104 (58 percent) were in the experimental structured active learning group and 76 (42 percent) were in the control group. Group composition did not differ significantly by class level, major, or gender.

Class time for each group was divided into three components: (1) 50-minute lectures presented by a professor three times each week; (2) four-hour labs facilitated by teaching assistants twice each week; (3) one-hour discussion sections conducted by a teaching assistant once each week. In contrast to the control group, the experimental section incorporated three instructional innovations: (1) students appointed a peer board of directors that shared power over all aspects of the course with the instructor; (2) open-ended laboratory projects, designed to simulate the practices of research scientists, replaced many standard laboratory experiments; (3) lectures incorporated communication between pairs of students and interactions between students and the instructor (Millar et al., 1995; Wright et al., 1997).

LEAD investigators collected data through several methods. To determine whether differences due to instructional method were apparent to faculty, researchers recruited faculty

[1]Data obtained from the Chem 110 archive of the Learning through Evaluation, Adaptation, and Dissemination (LEAD) Center, 1402 University Avenue, Madison, Wisconsin 53706.

members (primarily from departments that offer courses for which the analytical chemistry course is a prerequisite) to evaluate the competence of students in the two sections. Of the 49 faculty members recruited by mail, 25 participated in the study. Eleven departments were represented, included chemical engineering, biochemistry, mathematics, pharmacy, and geology.

Faculty evaluated students through individual oral examinations that lasted approximately half an hour each. Criteria for determining competence were left to the discretion of each faculty member. Researchers collected data on faculty's criteria through an open-ended survey and an individual interview and analyzed criteria *post-hoc*. The competence item was measured on a six-point scale (where 1=disagree and 6=agree) as follows: "Taking into account all the criteria formulated in my oral exam preparation exercise, this student demonstrated overall competence."

Several controls for confounding influences were operationalized. To control for the possibly confounding influence of differences in students' precourse characteristics, students were divided into eight groups of approximately 24 each based on their gradepoint percentile in the prerequisite first-semester introductory course. Each faculty member examined approximately eight students (proportionally representing each section) within the same gradepoint octile. Neither students' section in the analytical chemistry course nor their gradepoint octile in the prerequisite course was identified to examiners. To control for the possibly confounding influence of instructor characteristics, LEAD researchers observed lectures for a total of 16 times during the semester to determine whether the instructional methods were implemented at comparable levels of proficiency. Researchers also conducted two one-hour, open-ended interviews with 39 students (proportionally representing men and women in different colleges by section) throughout the spring 1995 semester to determine whether students perceived comparable instructional proficiency between sections (Millar et al., 1995; Wright et al., 1997).

The spring 1995 interviews with students also addressed whether they perceived that the coursework affected their abilities to relate concepts and applications. These qualitative measures were triangulated with data from a follow-up survey in December 1995 (seven months after completing the course). The survey included 34 Likert-type items and five open-ended questions. Participation in the follow-up study was quite high, with 114 alumni of the course (63 percent of the original sample) responding to the items employed for this analysis. Respondents and nonrespondents did not differ significantly by group, class level, major, gender, or gradepoint percentile in the prerequisite course (Millar & Squire, 1996). The dependent variable for this analysis was a three-item scale ($\alpha = .81$) measuring students' perceptions that the analytical chemistry course integrated lecture and lab, had real-world applications, and related theory and practice (see Table 1).

Insert Table 1 about here

I analyzed the spring 1995 interviews and observations, and the December 1995 open-ended survey questions, by identifying, describing, and presenting relevant themès and trends. Quantitative assessment of faculty perceptions of student competence proceeded with an analysis of variance (ANOVA) that modeled the outcome by method by gender. Gradepoint octile in the prerequisite course was not included in this analysis because the faculty evaluation design controlled for this difference in students' precourse characteristics. I employed a second ANOVA, modeling the outcome by method by gender by gradepoint octile in the prerequisite course, to measure students' perceptions of the impact of the course on their abilities to relate concepts and applications seven months later.

Results

Table 2 shows that the instructional method had a statistically significant ($p<.001$) effect on faculty assessments of students' competence and that the effect did not differ significantly by gender. Results of Levene's test for homogeneity of variance suggested that the distributional assumptions underlying ANOVA were not violated (p>.43). The mean competence rating for students who participated in structured active learning was 4.79, compared with 4.17 for students in the control group. The instructional method explained about 6 percent of the variance in the outcome measure (r^2=.059), an effect size of half (.50) a standard deviation[2] or a 19 percentile point between-group difference. In other words, the average (50th percentile) student in the experimental group was judged by faculty as more competent than 69 percent of the students in the control group.

Insert Table 2 about here

Qualitative data supported the inference of method-related differences in faculty assessments of students' competence. Observations of lectures and interviews with students resulted in LEAD researchers concluding that each instructional method was implemented at a high level of competence. Thus, potential differences in instructional proficiency were unlikely to have biased the results.

The *post-hoc* analysis of criteria employed by faculty to assess students' competence suggested that the difference between sections was most apparent to a group of 11 assessors who focused on whether students comprehended the larger context surrounding a problem and demonstrated an understanding of the relationship between theory and practice during the problem-solving process. One faculty member, for example, assessed " . . . how quickly they could take that information and synthesize it into a new situation." A second assessor evaluated whether students could "... apply that to a new situation, and how comfortable were they moving on to

[2] $\text{Effect size} = \dfrac{2r}{\sqrt{1-r^2}}$

that." A third recalled that, "I just said, 'Tell me about electrochemistry,' so my criterion was really how well could they just have a general discussion about that and explain to me the concept of what was important about it and what might be some applications of it. So it was to see if they got the big picture or if they could only draw a little diagram and not really know what to do with it."

The effect of structured active learning on students' perceptions of their ability to relate concepts and applications seven months after completing the course was even more dramatic. Table 3 shows that the method-related effect was statistically significant ($p<.001$), controlling for students' gradepoint percentile in the prerequisite course, and that the effect did not differ significantly by gender. Results of Levene's test for homogeneity of variance again suggested that the distributional assumptions underlying ANOVA were not violated ($p>.22$). The mean perceived ability to relate concepts and applications among students who participated in structured active learning was 4.96, compared with 3.47 for students in the control group. The instructional method explained nearly 32 percent of the variance in the outcome measure ($r^2=.316$), an effect size of 1.37 standard deviations or a 41 percentile point between-group difference. The average (50th percentile) student in the experimental group perceived a greater ability to relate concepts and applications than 91 percent of the students in the control group.

Insert Table 3 about here

Data from the spring 1995 interviews suggested that students who participated in structured active learning were aware that concepts and applications were related in their coursework. One student commented that, "I mean, we'd do the labs and we're like, 'Oh look how this relates to the lecture!' (laugh) I mean it was a totally unique thing really that lab and lecture went along so well."

Other students focused on the cooperative element of the coursework, one noting that, ". . . with our group projects, it really reinforced what we were learning in the lectures."

Students' responses to the open-ended questions on the follow-up survey were even more explicit in describing how structured active learning was associated with their ability to relate concepts and applications. A student wrote that the professor "integrated concepts and real-life experiments. Being able to design our own experiments really helped me understand the material and have a sense of accomplishment!" Another noted that the class "was probably the best class I have had so far. It was experimental, focusing on group work and real-world applications, which made it useful and interesting."

Although students in the control group gave their professor high marks for instructional expertise, many reported that the coursework was not interrelated. The disjuncture between lectures and labs was most apparent. As reported by one interviewee, "Lecture is there to learn the concepts behind everything. Lab you just kind of copy down some equations and use them, and you might ask what they mean, but you really just want to get the calculations done." Students generally saw no alternative, however. Another interviewee said, "I don't know, I guess I feel like there is a gap between lecture and lab but I don't know how we could really do in lab what we're discussing in lecture."

Several students in the control group noted their frustration with the lack of association between theory and practice in their responses to the open-ended questions on the follow-up survey. One wrote that, ". . . as for the real world applications, I feel it was very poor. Students were taught an equation and what it meant, but never how to apply it." Another reported, "After memorizing all the equations last semester, I don't even understand the concepts behind them . . ."

Conclusions

This study is limited primarily because of the lack of randomized assignment to groups and the possible confounding influence of different instructors. In addition, data are from a single institution and represent only one experimental and one control group. Replication in other contexts would increase the external validity of the results. Longitudinal analyses employing a greater variety of pre- and post-tests might also provide insight to the influence of students' aptitudes and learning styles, as well as method-related effects, on a greater variety of learning outcomes.

Despite these limitations, the study has several implications for researchers, faculty, and policy makers interested in education reform. The results suggest that students who participated in structured active learning perceived a greater ability to connect abstract concepts and real-world applications than students who participated in a relatively traditional instructional program. Importantly, students perceived significant instructional effects more than half a year after completing the course.

In addition, faculty from a broad range of disciplines also perceived that students who participated in structured active learning were more competent than their counterparts in the traditional program, particularly in comprehending the larger context surrounding a problem and understanding the relationship between theory and practice during the problem-solving process. Moreover, the positive effect of structured active learning on students' abilities to connect concepts and applications extended to men and women. Open-ended laboratory projects and groupwork appeared particularly important in facilitating the learning outcome. Students generally reported that working in groups on open-ended projects helped them apply the concepts that they studied during the lectures. Several participants in structured active learning noted that they felt a sense of accomplishment from working on realistic problems.

The multiple methods of assessment employed in the study also have implications for researchers and faculty. Quantitative and qualitative analyses are both important in representing teaching and learning inside and outside the classroom. The former can be valuable in assessing specified outcomes, while the latter can provide the detail necessary to understand how participants perceive the process. Finally, involving faculty from several departments in assessing the effects of the course might have resulted in greater openness to instructional innovation among those educators, many of whom had previously expressed skepticism of educational reform in general. One faculty member adopted structured active learning for the first time during spring 1996. Those considering similar projects might benefit by involving a comparably broad range of faculty in designing and implementing their assessment.

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Table 1. Scale for assessing the effects of instructional method on students' perceived ability to relate concepts and applications.

Items
[This course] helped me understand how to apply chemistry to real world issues.
In this course I discovered the value/use of concepts by utilizing them to solve problems.
In this course I was able to integrate what I learned in lecture and lab.

Note. Six-point scale, where 1=disagree and 6= agree. $\alpha = .81$.

Table 2. Analysis of variance for the effects of instructional method on faculty assessments of students' competence.

Source of Variation	*df*	Mean Square	*F*
Total	179	1.577	
Explained	3	6.235	4.162**
Main Effects	2	8.640	5.767**
Method	1	17.074	11.398***
Gender	1	.541	.361
2-Way Interaction	15	1.427	.953
Method X Gender	1	1.427	.953
Residual	176	1.498	

*$p<.05$. **$p<.01$. ***$p<.001$.

Table 3. Analysis of variance for the effects of instructional method on students' perceived ability to relate concepts and applications.

Source of Variation	*df*	Mean Square	*F*
Total	113	1.679	
Explained	30	2.826	2.236**
Main Effects	9	8.205	6.492***
Grade	7	1.764	1.396
Method	1	56.985	45.089***
Gender	1	.483	.382
2-Way Interactions	15	.562	.445
Grade X Method	7	.647	.512
Grade X Gender	7	.631	.499
Method X Gender	1	.121	.095
3-Way Interaction	6	.419	.332
Grade X Method X Gender	6	.419	.332
Residual	83	1.264	

Note. Grade refers to students' gradepoint octile in the prerequisite introductory course.
*p<.05. **p<.01. ***p<.001.

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