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Student Peer Teaching: An Innovative Approach to Instruction in Science and Engineering Education

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This paper reports the results of a pilot-study in a senior paper science and engineering class, of an innovative instructional method designed to foster student problem-solving and in-depth learning of material, namely, student peer teaching. We review related literature focusing on active learning methods in science and engineering education, describe the method of student peer teaching used in this pilot-study, present the evaluation method and results, and discuss implications for further development of this method of instruction. Results suggest that students were able to effectively teach significant curricular content. In addition, the method of student peer teaching served important purposes in helping students develop in-depth understanding and expertise in the issues related to their teaching session, as well as teaching and presentation skills which will be useful in their professional practice. However, students expressed concern that, while achieving in-depth learning of the content of their teaching session, they tended to focus on the content area of their teaching session at the expense of other content areas and may not have learned as well from other students as from the Professor. We recommend a modified structure for student peer teaching which incorporates cooperative learning methods; increased Professor involvement in class sessions, in the role of the mentor; and modifications in performance evaluation methods to ensure ongoing student monitoring of progress and self-assessment. The method of student peer teaching, in science and engineering education, combined with cooperative learning methods, is viewed as a major extension of cooperative learning methods, used in the service of preparation for professional careers.

KEY WORDS: Science; engineering; education; student; peer teaching; cooperative learning.

INTRODUCTION

In applied science and engineering higher education, the most important purposes are for students to learn fundamental concepts and principles, and their application both in creative problem solving, and in the design or development of new products or processes. Despite these purposes, which would require students to engage in active problem solving, we, as educators in science and engineering, tend to use lecturing as our principal method of instruction, while students passively take notes to encapsulate our commentary. This traditional method of lecturing, and related note-taking, which prevails in our science and engineering classrooms, does not encourage students to actively participate in in-depth learning of the content. Also, it does not foster student learning of essential problem-solving skills in a collective team or group environment. In advanced engineering design classes, most commonly, students are formally involved in in-group design projects, only during the last semester before graduation.

The purpose of this paper is to report the results of a pilot-study in a senior paper science and engineering class, of an innovative instructional method designed to foster student problem-solving and in-depth

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learning of material, namely, student peer teaching. Paper science and engineering college programs combine education in chemistry and engineering as a basis for educating students in using principles of chemistry and engineering in the manufacture of paper and paper products. In this paper, we review related literature focusing on active learning methods in science and engineering education, describe the method of student peer teaching used in this pilot-study, present the evaluation method and results, and discuss implications for further development of this method of instruction.

PERSPECTIVES FROM LITERATURE

The goals of education for the professions include acquisition of bodies of specialized knowledge, but equally important, skills in applying this knowledge in the complex situations of practice, including communication skills and skills in working in teams (Harris, 1993). These goals suggest the need for instructional methods, which foster active learning and problem solving (Harris, 1993). Smith (1998) describes the nature of engineering expertise, which suggests the importance of both specialized bodies of knowledge, as well as application of knowledge in the complex situations of engineering practice. He suggests four strategies for development of engineering expertise, including problem-based learning, cognitive apprenticeship, reflective practicums, and cooperative learning. These strategies emphasize the importance of learning through solving problems, with mentors and peers.

A variety of active learning methods have been reported in the literature of science and engineering education. For example, Ziems and Neumann (1997) describe the use of interactive problem-solving exercises. Sanders (1995) describes the use of a semester-long design project, team exercises, and field trips to enhance student learning and interest in an environmental engineering course. Richards and his colleagues (1995) propose the use of cases and instructional modules to teach invention, engineering design, and technology management. Pavelich and his colleagues (1995) describes the use of open-ended, real world problems prepared by government agencies and private companies that interact as clients with student teams, in a program designed to foster intellectual development, teamwork, and communication skills.

Problem-based learning, which has been well developed in health profession education (Barrow and Tamblyn, 1980) has been increasingly used in other professional education, generally, to structure curricula. This approach to professional education centers on use of the problems of professional practice to provide a stimulus for learning the specialized bodies of knowledge of a profession. In the context of science and engineering education, Kolmos and her colleagues (1996) characterize problem-based learning at a theoretical and a practical level. Woods and his colleagues (1996) describe the use of problem-based learning in a chemical engineering class.

Peer teaching has been widely used in education generally to enhance students' learning. There is extensive evidence that peer learning and teaching is effective for a wide array of goals and content (Johnson and Johnson, 1975; Johnson *et al.*, 1981). Peer teaching has been found to benefit the student-teachers, because preparing to teach involves in-depth study of material, analysis, and selection of key concepts into one's own words. Yet, there have been few reports in the literature of science and engineering education of the use of peer teaching. Magin and Churches (1995) describe the successful use of peer tutors in use of computer software for engineering design.

A widely used variant of peer teaching is the instructional methodology of cooperative learning (Johnson and Johnson, 1975). Cooperative learning is the use of small student groups as teams to accomplish a common goal, emphasizing positive interdependence, individual and group accountability, face-to-face interaction, team skills, and group processing (Smith 1996). In cooperative learning, students learn material by teaching to, and learning from, each other in a team context. Ross and Fulton (1994) describe the use of cooperative groups in an analytical chemistry course, to help students become active learners. Karl Smith, a leader in engineering education, has collaborated with the Johnsons, in explorations of the applications of cooperative learning (Johnson *et al.*, 1991).

In this paper we report a pilot-test of the use of one method of active learning, namely, student peer teaching of core content, which has not been widely used in science and engineering education. Moreover, in analyzing the results of this study and considering modifications of the method, we recommend incorporating within the student peer teaching approach significant components of cooperative learning, as described by David and Roger Johnson and Karl Smith (Johnson and Johnson, 1975; Johnson *et al.*, 1991).

METHODS OF STUDENT PEER TEACHING

Students in a senior level course in the field of paper science and engineering were required to teach a small portion of the subject matter to their fellow classmates. Initially, the instructor spent 4 weeks covering the basic principles and concepts in the course. Then, the subject matter in the syllabus was divided into a number of discrete units. Students in the class selected topics of individual interest from among these units. Each student had approximately a month to prepare for his or her teaching session with the class. The approximate time period allotted for each student's actual teaching session was about 20–25 min.

After each student had selected their sections for teaching, the Professor provided mentoring for each student, through individual discussions of the subject matter, the relative importance of various topics within the subject matter, sources of additional information, and strategies for teaching. The Professor encouraged students to use teaching strategies that would engage the class in active learning through discussion. This one-on-one mentoring, which took about 2 h of discussion between the instructor and each student, was intended to allow students to gain confidence in their knowledge of the subject matter, and to see a transformation in themselves from being novices to having significant expertise with the subject matter. In addition to the time spent with the instructor in the mentoring session, students by themselves spent approximately 10–20 h studying and learning the material in preparation for their teaching session.

One important goal of this instructional strategy was to encourage active learning and participation of all students in the class. In fact, prior to beginning this pilot-study, it was expected that students may be more at ease in asking questions and participating in class discussions if their fellow classmates were "up on stage" instead of the Professor. Therefore, students were informed at the beginning of the class that they were expected to participate in their colleagues' teaching efforts through asking questions, and contributing to the class discussion. Each and every student was expected to come prepared for each class session by prior reading of the subject matter in the textbook.

During each student-teaching session, the Professor participated in the class in a dual role. He sat among the class as a student, making comments and asking questions. In addition, he attempted to facilitate class discussion by asking questions of the students and generally encouraging active participation of all students.

The teaching performance of students was evaluated by their fellow classmates, as well as the Professor, using a performance rating form described in the next section. This method of evaluation was intended to enhance learning through detailed student peer feedback. Evaluation of the student-teaching session comprised 50% of the total grade for this class. The other 50% of the grade was assigned based on students' performance on the final examination at the end of the quarter. This grading distribution was intended to reflect the significant effort required of students to prepare for their teaching session, as well as the significant learning expected to be associated with preparing for the session.

EVALUATION OF STUDENT PEER TEACHING METHOD

We used two methods to evaluate the student peer teaching method of instruction: (1) evaluation of students' instruction by their peers and the Professor and (2) evaluation by all students of the effectiveness of this teaching method. Evaluation of students' instruction by their peers, and the Professor, is viewed as one marker of the effectiveness of the student peer teaching method.

Evaluation of Students' Instruction

For each student teaching session, a total of 11–13 students, as well as the Professor, participated in evaluation of the session, using a 5-point scale (5 = *Excellent*, 4 = *Very Good*, 2 = *Fair*, 1 = *Poor*) for each of the evaluation criteria listed in Table I. Table I shows the following for each evaluation criterion: the mean rating, overall (including the students and the Professor); the mean rating for student-evaluators only; and the mean rating for Professor only. In addition, the mean total points and total percentages are shown with 40 being the highest possible total points. The overall average for the class, for all criteria, ranged from a low of 3.16 to a high of 3.97, indicating, on average, good to very good performance on all criteria. These results suggest that students were able to effectively teach significant curricular content.

It is noteworthy that the overall means, for each criterion, and for the overall performance and total

Table I. Mean Evaluation of Students' Teaching, Overall, Student Evaluator Only, and Professor Only[a]

Criteria for evaluation	Overall mean	Student-only mean	Professor
Clarity in discussing and presenting material	3.81	3.82	3.71
Overall quality of visuals	3.97	3.97	3.93
Knowledge of subject matter	3.85	3.84	4.00
Student (class member) level of learning from teacher	3.58	3.57	3.68
Student-evaluator level of preparation for session	3.16	3.09	3.89
Answering questions	3.46	3.45	3.57
Stimulating student active participation and proble	3.28	3.29	3.29
Overall teaching performance	3.87	3.84	4.18
Total points (highest possible = 40)	28.98	28.89	30.25
Total percentage (of 40 points)	72.47	72.20	75.66

[a]Scale: 5 = *Excellent*, 4 = *Very Good*, 3 = *Good*, 2 = *Fair*, 1 = *Poor*.

points, for student-evaluators only and the Professor only, were not significantly different. Using the Professor's ratings as the "gold standard" for performance assessment, this finding suggests that students serve as accurate evaluators of their peers; the trend for the Professor to evaluate students somewhat more positively on each criterion indicates that student-evaluators may be "tougher" evaluators than the Professor.

The quality of visual aids received the highest mean rating, and the highest rating for all student-instructors, indicating university students' general proficiency in developing computer-aided graphics. Other criteria on which students received the highest mean ratings, overall, were knowledge of subject matter ($m = 3.85$); clarity in discussing and presenting material ($m = 3.81$); and answering questions ($m = 3.46$). These relatively high mean ratings reflect the substantial mentoring and student effort devoted to preparing their presentations. Students received the lowest mean rating on the criterion of stimulating student active participation. It may be that, while focusing on development of in-depth content knowledge, and translating their knowledge into a succinct presentation format, student-teachers gave less attention to planning teaching strategies to stimulate class participation and student problem solving. It is noteworthy that students in the class, on the average, gave the lowest mean rating to their own level of preparation for participation in the class ($m = 3.16$). This result, which was consistent for all student instructors, confirms a common problem faced by teachers in higher education, namely, students not completing recommended reading assignments in preparation for class. This situation may also help to account for the difficulty student instructors had in stimulating student active participation in class.

Student Viewpoints

Students' viewpoints were obtained at the end of the quarter, using an evaluation form consisting of two parts: (1) structured questions concerning the overall value of the teaching method for student learning, the value of the lecture preparation sessions with the instructor, and the effectiveness of students evaluating each other and (2) open-ended questions concerning the strengths, the weaknesses, and recommendations for change in using this instructional method. Responses to structured questions were analyzed using descriptive statistics. Responses to open-ended questions were analyzed using standard approaches to identifying themes in qualitative data (Miles and Huberman, 1994).

Students were most positive about the value of the mentoring sessions with the Professor ($m = 3.43$) and they were also positive about the value of the teaching session for their own learning ($m = 3.07$); students were generally negative about students evaluating each other, particularly if these evaluations comprise a significant percentage of the grade ($m = 2.5$), with 53% of students rating this experience as "4 = *Fair*." A content analysis of students' comments provides a more in-depth analysis of students' views of the strengths and weaknesses of this instructional methodology, as well as suggestions for improvement which as one student commented, *"With a little fine tuning, this method can be very effective."*

When asked whether, overall, the use of this instructional method was "worth the effort" the majority of students responded, "yes." The most important benefit cited was students' developing substantial in-depth understanding and expertise in the subject area of their teaching session. Typical comments included *"Students are required to gain a fundamental understanding of a specific topic." "Each student studies in* *depth a certain topic and becomes and 'expert' in this area" "Opportunity to do research on a topic . . . forced me to learn the topic better than if I was just going to be tested on it."* The other important benefit cited by students was developing teaching and presentation skills. Typical comments included *"Opportunity to do a professional presentation can only help a student prepare for the 'real' world." "In the future, you might have to give seminars, lectures etc. So it's good to have practice . . . gave each student some awareness as to how a presentation should be researched and developed." "Approached presentation as if it were a real life speech. Learned how to use PowerPoint, and I benefited from this teaching method."*

From student's perspectives, there are three major weaknesses of this instructional method, as implemented in this situation. While each student develops an in-depth understanding of the subject of their teaching session, the class may not learn as well from the students as from their Professor. Typical comments included *"May be difficult to learn from other students. Their teaching skills are not as good as yours, and it's difficult to know what to pay attention to, what is the most important information, etc. Also no relevant industry experience to tie to topics." "Students are not experts in area of study. Thus, they're unable to bring unique ideas and information to the class."* Second, in their allocation of time for a course, students may focus on the content of their teaching session at the expense of other content. A typical comment was *"Students may focus on their topics alone; and may not be as interested in others' topics."* In addition, students expressed concern about several evaluation issues. While they generally viewed the experience of preparation for teaching and actually conducting their session as valuable, they did not believe that it should comprise half of their grade. While they valued their peers' feedback, they expressed strong concern about students' evaluations of their teaching session contributing to their grade in the course. Our analysis of the Professor's rating demonstrates that, in fact, there were no significant differences in the Professor's and the students' mean rating. Yet students perceive that only the Professor has the requisite expertise and objectivity to grade them fairly. Typical comments include *"The instructor should be the only one who evaluates because he/she knows the goals of the experience to evaluate the content of the seminars." Evaluations by students should only be used as a guide to assist the Professor in determining the actual grade. Student evaluations should be used primarily as a method for presenters to get feedback from their peers." "The Professor is more objective in evaluation of student performance. Not only do student likes/dislikes affect grading, but so do individual expectations . . . what it boils down to is that student evaluation is overly subjective."*

Students had a number of suggestions for improvement, and fine-tuning the use of this instructional method, so that its benefits could be preserved—the benefits of student in-depth learning of the topic of their teaching session, and student development of presentation and teaching skills, which will be valuable in their professional practice—while ameliorating the problem. First, students suggested that for each class session the teaching time should be equally divided between the student-instructor and the Professor, with the Professor discussing details left out, "driving home" the most important details, and providing insights from experience. Second, students suggested having periodic quizzes to make sure that they are keeping current with all course content, and reassure them that they are making appropriate progress. Third, students suggested that student-instructors be mandated to include in their sessions teaching strategies designed to stimulate class participation, such as use of cases. One student commented, *"Teaching sessions could be improved by having more cases—linking real world situations to what we are learning."* Finally, one student suggested potential benefits from students doing presentations in teams, commenting, *"Have teams of possibly three students do presentations. I learned a lot about material I presented. If I present more, I learn more. Also the team environment is important."* Such an instructional approach would combine the benefits of student peer teaching with cooperative learning (Johnson and Johnson, 1975).

DISCUSSION

The purpose of this paper is to report the results of a pilot-study in a senior paper science and engineering class, of an innovative instructional method designed to foster student problem-solving and in-depth learning of material, namely, student peer teaching, and to make recommendations for modifications in this method, based on evaluation of its effectiveness. The evaluation results demonstrate that this instructional method served important purposes in helping students develop in-depth understanding and expertise in the issues related to their teaching session, as well as teaching and presentation skills which will be useful in their professional practice.

Nevertheless, students' comments also suggest that fine-tuning of this method is needed, in order to serve the purposes intended—for students to learn fundamental and applied science and engineering concepts and principles, in a collective team or group environment. Basically, students expressed concern that while achieving in-depth learning of the content of their teaching session, they tended to focus on the content area of their teaching session at the expense of other content areas, and they may not have learned as well from other students as from the Professor.

We recommend a modified structure for student peer teaching which incorporates the following: co-operative learning methods; increased Professor involvement in class sessions, in the role of mentor; and modifications in performance evaluation methods. Each student would be assigned to two or more teams to plan presentations of several content areas; teams would be charged to create and use case-situations as a stimulus for discussion during their teaching session. The first half of each class session would be devoted to team teaching; during the second half, the Professor would discuss details left out, "drive home" the most important concepts, and provide perspectives from experience. The Professor would thereby play the role of mentor, coach, and expert in the profession. In addition, the Professor would schedule biweekly case-based evaluation of students' applied knowledge of content covered during the previous 2 weeks, to stimulate students to keep up-to-date in their learning in all content areas and to provide them with feedback on their progress. Finally, students' performance in the team-teaching sessions, as well as in the entire course, would be graded only by the Professor. For each team-teaching session, the entire class would complete rating forms to evaluate the teaching session, but these forms would be used only for feedback to the teams, rather than contributing to students' grades for the course. This modified structure for student peer teaching is shown in Fig. 1.

Students in the class as a whole would benefit from the well-known advantages, in professional education, of learning through problems and cases (Barrow and Tamblyn, 1980). The Professor would play a more active role during class sessions, so that students in the class as a whole would derive the well-known benefits of mentoring from a seasoned professional (Schon, 1983). More frequent evaluation of students' knowledge would provide the well-known benefits of on-going student self-assessment (Mehta, 1995).

Through this structure, each student would achieve in-depth learning in several content areas, *through* preparing their teaching presentation in a cooperative learning group, *and* through the experience of teaching. The method—of students learning through teaching and preparing for their teaching session in cooperative learning groups—is a significant extension of cooperative learning approaches, which is particularly valuable in professional education. In the professions, part of the individual's professional responsibility is typically teaching colleagues and clients. For example in engineering, design problems are solved as teams; once solved, individual and teams must communicate, and teach their solutions to other colleagues and clients. In engineering education, it has been common for students to solve design problems in cooperative learning groups (Smith, 1996), but it has not yet been common to teach the basic and applied sciences, such as chemistry in

1. Assignments: Assign each student to two different teams to plan a class teaching session of selected content areas.
   Charge to develop cases and questions to stimulate class discussion.

2. Preparation: Allow one class session per week for team preparation of their teaching session.

3. Each Class Session:
   - First Half: Team teaching of selected content, using cases to involve class discussion.
   - Second Half: Professor mentoring, by discussing details left out, "driving home" the most important concepts, and providing perspectives from experience.

4. Evaluation:
   - Bi-weekly case-based evaluation of content covered during prior two weeks – to stimulate students to keep up-to-date and provide feedback on their progress.
   - Professor evaluation of team teaching sessions, informed by feedback from entire class on effectiveness of teaching.

Fig. 1. Model for Student Peer Teaching in Cooperative Learning Teams.

paper sciences, in cooperative learning groups. Typically, in cooperative learning groups, students maximize their learning through teaching each other; the results of their learning are documented in presentations they make as a group. In the approach we are recommending, the major task of the cooperative learning groups is preparing for teaching the entire class, which involves consideration of "teaching issues" such as the goals for the teaching session and appropriate instructional methodology. In conclusion, we outlined a number of recommendations for the most effective use of student peer teaching. First we are impressed with the teaching potential of having students do their presentation in teams, thereby combining the benefits of student peer teaching with cooperative learning (Johnson *et al.*, 1991), so that students will achieve in-depth learning of several content areas, in a team context. Second, in student–instructor teaching sessions, the Professor should play a more active role by discussing details left out, "driving home" the most important concepts, and providing insights from experience. Third, Professor should incorporate ongoing evaluations, to make sure that students are keeping current with all course content, and also to reassure them that they are making appropriate progress. Through these methods, the significant benefits of student peer teaching may be preserved, and enhanced, through the well-known benefits of cooperative learning methods and faculty mentoring. These instructional methods are viewed as particularly beneficial in professional education, because a major component of work in most professions is teaching colleagues and clients.

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