Cooperative Learning of Neutron Diffusion and Transport Theories

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Abstract

A cooperative group instructional strategy is being used to teach a unit on neutron transport and diffusion theory in a first-year-graduate level, Reactor Theory course that was formerly presented in the traditional lecture/discussion style. Students are divided into groups of two or three for the duration of the unit. Class meetings are divided into traditional lecture/discussion segments punctuated by cooperative group exercises. The group exercises were designed to require the students to elaborate, summarize, or practice the material presented in the lecture/discussion segments. Both positive interdependence and individual accountability are fostered by adjusting individual grades on the unit exam by a factor dependent upon group achievement. Group collaboration was also encouraged on homework assignments by assigning each group a single grade on each assignment. The results of the unit exam have been above average in the two classes in which the cooperative group method was employed. In particular, the problem solving ability of the students has shown particular improvement. Further, the students felt that the cooperative group format was both more educationally effective and more enjoyable than the lecture/discussion format.

Introduction

A cooperative group strategy was used to teach a unit on neutron transport and diffusion theories in a first-year-graduate level, Reactor theory course taught at the Bettis Atomic Power Laboratory. The Reactor Theory course is part of an accelerated training program offered at the laboratory that is similar in level and content to a masters degree program in nuclear engineering. Students complete twelve courses with a total of approximately 700 classroom hours during a 24 week period. Much highly complex, technical material is communicated in that short time period.

Historically, the unit covering transport and diffusion theories has been one of the most challenging for students. Although all of the students have at least an undergraduate degree in engineering, science, or mathematics, only a few students have a degree in nuclear engineering. Thus, for most of the students, Reactor Theory is a new area of study. The unit on transport and diffusion theories involves some of the most complex subject matter in the Reactor Theory course. The equations of state typically involve seven independent variables, and employ mathematics on the level of integro-differential and partial differential equations. The scores on the unit examination for the transport and diffusion topics have resulted in the lowest average score of any unit in the course sequence. In particular, students have had more difficulty solving exam problems (which are typically an extension or a level higher than class and homework assignments) than in answering essay questions.

The unit covering transport and diffusion theories, formerly presented in the traditional lecture/discussion style, was implemented instead using elements of both formal and informal Cooperative Group methods [1]. A cooperative instructional strategy was adopted because of the positive results that have been obtained in a large variety of educational contexts. In particular, the effectiveness of cooperative strategies has been demonstrated for educational objectives that involve highly complex problem solving. Johnson & Johnson state that, "The more conceptual and complex the task, the more problem solving required . . . the greater the superiority of cooperative over competitive and individualistic learning" [2]. Cooperative group strategies are also reported to be effective when used for instruction in scientific and engineering disciplines. Johnson, Johnson, & Smith cite the results of a recent meta-analysis of research on the use of small group instructional strategies (that were "predominantly cooperative") for learning objectives in "science, mathematics, engineering, and technology" [3]. That meta-analysis demonstrated that, "small-group learning had a significant and positive effect on undergraduates' achievement, persistence, and attitudes" [3].

The purpose of this study was to determine the effects on students' achievement and attitudes of presenting the unit covering transport and diffusion theories in a Cooperative Group format. The cooperative instructional strategies used in the unit are described in the next section. The results and conclusions of the study are presented in the final sections.

Instructional Strategies

Although the curricular content of the transport and diffusion unit remained unchanged, substantial changes in instructional strategies were necessary. In particular, changes were made in the structure of classes and the role of the instructor. Incentives and provisions for cooperative teamwork were added to implement the cooperative strategies. These instructional strategies are further described in this section.

The structure of the classes was modified extensively with the adoption of the cooperative strategy. The transport and diffusion unit previously consisted of seven classes that were each two hours in length. An eighth class was added to accommodate the cooperative exercises. In the old format, the instructor would begin each class with a review lasting approximately 15 minutes, followed by the presentation of new material using a lecture/discussion format. In the Cooperative classes, the introductory reviews were abbreviated and supplemented by Advance Organizers[4], short summarizes of the new information to be presented in the lesson. The reviews were most often conducted by the instructor, but occasionally would be assigned to a student selected randomly from the class. The summary and Advance Organizers were followed by either a lecture/discussion segment or a cooperative group exercise. The initial introductory lecture/discussion segment in the unit is approximately 1.5 hours in length. However, all subsequent lecture/discussion segments are shorter, lasting an average of approximately 30 to 40 minutes. The lecture/discussion segments were punctuated by ten cooperative group problem solving exercises during the course of the unit. During these exercises the instructor observed the groups, and guided their problem solving processes by offering hints and assessments of progress.

The cooperative group problem solving exercises ranged from 20 to 50 minutes in length, with an average length of approximately 30 minutes. These exercises were designed to require the students to elaborate, summarize, or practice the material presented in the lecture/discussion segments. For instance, in an exercise intended to elaborate on a qualitative presentation of the Boltzmann Transport equation for neutrons, students were asked to develop the precise functional forms for the terms in equation. The students were first given five minutes to consider the problem individually. The students were then given approximately 25 minutes to develop a cooperative group solution. During this period, students also prepared an overhead transparency that could be used in the presentation of their solution to the class. At the end of the period, a single student was chosen randomly to present the solution developed by his or her group. This pattern of individual reflection and cooperative group problem solving followed by random student presentations was followed in the cooperative exercises throughout the unit.

The cooperative groups were chosen to be heterogeneous groupings of two or three students whose membership remained fixed throughout the unit. The instructor has chosen the membership in the groups in the cooperative classes in two ways. In the first class to use the cooperative strategies, group membership was chosen primarily to provide each group with nearly equal capabilities in mathematics and engineering, as measured by the performance of the students in previous courses. A secondary consideration was the preservation of existing groups that had previously been formed as design teams for another course. Although this method worked well, for the second class the group memberships were chosen solely to preserve the existing groups. This choice was made to take advantage of the established patterns of communication and problem solving that had previously developed in the existing groups. There is some evidence that adopting the existing groupings was not as effective as originally envisioned. This evidence will be discussed in the next section on results.

Cooperative group activity was also encouraged outside the classroom. Specifically, groups were encouraged to collaborate in studying for examinations and in completing homework assignments. Students were given the option of either submitting a single set of homework solutions for the group, or submitting sets of homework solutions prepared by individuals. However, if the group chose to submit solutions as individuals, one of the submittals was randomly chosen for the purpose of assigning the group a grade for the assignment. (All homework solutions submitted by the students were critiqued by the instructor and returned to the students.)

Students were encouraged to cooperatively study for examinations by adjusting each individual's grade on the unit exam by a "group achievement" factor, which depended on the performance of all of the group members. Two different group achievement incentives have been used. In the first class to use cooperative strategies, individual grades on the unit examination were adjusted according to the formula

Individual's Final Grade = Individual's Exam Grade * (Group's Average Exam Grade / 77.65)

The factor 77.65 is the historical average grade on the second exam, prior to implementing cooperative instructional strategies. Thus, grades were subject to being increased or decreased based on the group's performance relative to the historical average. Some students objected to this formula because their grades could decrease due to poor group performance. In the second class that used cooperative strategies, each group member's exam grade was increased by four percent only if all group members scored four percent higher than they scored on first exam in the course (or scored above 90%). Although the second incentive proved to be a more challenging criterion than the first, the second incentive was viewed more favorably by the students.

The characteristics of the groups used for the transport and diffusion unit are typical of both 'formal' and 'informal' cooperative groups. According to Johnson, Johnson, & Smith, informal cooperative groups are typically exist for a few minutes during class to discuss an issue or solve a problem of short duration [5]. Informal cooperative groups are often used to ensure that students are actively processing the material presented in the lecture segments. This is precisely the primary purpose of the cooperative group exercises performed during the classes in the transport and diffusion unit. In contrast, formal cooperative groups are usually longer in duration ("one class period to several weeks"). Formal cooperative groups are organized around specific "learning goals and jointly complete specific tasks and assignments." [6]. As in formal cooperative groups, the cooperative groups remained in place for the duration of the transport and diffusion unit. Further, the goals of the groups extended beyond the active processing of material presented in class. The completion of homework assignments cooperatively, and cooperative study for the unit examination were also encouraged.

The initial implementation of the cooperative instructional strategy in the Reactor Theory course included all of the five elements that characterize cooperative groups: "positive interdependence", "individual accountability", "face-to-face promotive interaction", "use of teamwork skills", and "group processing" [6]. Positive interdependence requires that the students believe that an individual group member can succeed only if his or her group succeeds. One of the strategies chosen to foster positive interdependence was the provision of a joint reward for group achievement on the unit examination. In addition, one of the joint goals of each cooperative problem solving activity was to develop a consensus solution to the problem. Upon the completion of each problem, a member of one group was chosen at random to present the group's solution using the overhead projector. Another of the joint goals of each group was to develop an overhead transparency that could be used for the presentation by any member of the group. Only one overhead transparency was distributed to each group. Limiting resources in this way encouraged the development of a consensus solution that could be presented by any member of the group. Cooperation on homework assignments was encouraged by assigning all of the group members the same grade for the homework assignment.

Individual accountability dictates that each individual must be held accountable for his or her own personal level of success; students should believe that they are able to succeed only through substantial personal effort [5]. One method of promoting individual accountability was by individually testing each student on the unit exam. Maintaining a small group size and the random selection of students to present problem solutions also fostered individual accountability.

Face-to-face promotive interaction requires that groups members directly aid the efforts of other group members [5]. For instance, face-to-face interaction implies that groups cannot be allowed to meet to divide an assignment into parts that are later completed individually. The small sizes of the groups, the heterogeneous nature of the groups (different group members possessed different areas and levels of expertise), and the nature of the tasks (the random selection of the representative of each group, the limiting of resources, joint system of rewards, etc.) were intended to motivate activities that would benefit other group members.

Participants in cooperative groups also need to be enabled and encouraged to apply the social skills that lead to effective teamwork. In addition, a cooperative group functions best when the group periodically processes or assesses "how effectively members worked together" [7]. During the first class to employ cooperative strategies, information on the characteristics of effective cooperative groups was provided in the form of several short lecture segments. Class time was allowed for group processing. The information and processing opportunities were not well received. In a survey performed after the completion of the unit, a substantial portion of the students (over 44 percent) were of the opinion that no time was necessary to build teamwork skills. The mood of those in opposition to spending time developing teamwork skills is expressed well by the following student comment, "By the time your are 21+ years old, you probably have already developed your social skills and group skills." There may be more opposition to, in one student's words, "wasting time" developing teamwork skills among graduate students than there would be among undergraduates. As a result, in the second class, the information on effective cooperative groups and processing opportunities were not included. In the final survey of that class, 60 percent of the students felt that developing teamwork skills was unnecessary. However, the performance of one group in that class may indicate that communications skills training would have been particularly useful. Presenting teamwork development opportunities in a manner acceptable to graduate students, even when the information would be of substantial benefit, may be problematic.

Results

The results of the unit exam have been above average in the two classes in which the cooperative group method was employed, but not significantly so at a 95 percent confidence level. The same instructor had taught the Reactor Theory course by the same approach (lecture/discussion) to 11 classes prior to implementation of the cooperative strategies in two classes. (The effects of the use of a single instructor on the internal and external validity of the study are discussed in Appendix 1.) A single factor ANOVA analysis was performed of the unit exam scores of the students in the 13 classes (see Table 1). Each class was treated as a separate group (i.e., 12 degrees of freedom). All unit exam scores are raw individual scores (i.e., prior to adjustments for cooperative group achievement). The results were significant at nearly the 90 percent level ($p=.1035$).

Source of variation	SS	df	MS	F	P-Value	F crit
Between Groups	1273.043	12	106.0869	1.589849	0.10346	1.8343 9
Within Groups	7940.593	119	66.72767			
Total	9213.636	131				

A plot of the average exam scores for the 13 classes is shown in Figure 1. The average of the exam scores in the cooperative classes was 83.00 percent, while the average of the lecture/discussion classes was 77.65 percent. The characteristics of the student population and the choice of measurement method are judged to have negligible effects on these results (see Appendix 1).

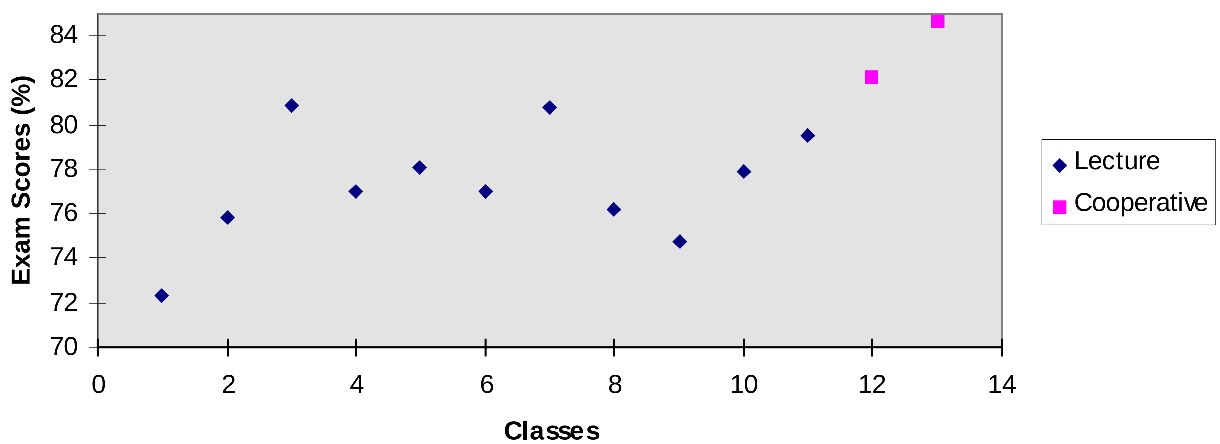

Figure 1 Average Unit Exam Scores for the Transport Diffusion Unit

The problem solving ability of the students appears to have shown particular improvement. Figure 2 presents a plot of the average scores on items on the transport/diffusion unit examinations that involved solving quantitative problems or deriving new results. Again, the scores reported are prior to adjustments using any cooperative group achievement factor. The average scores on the problem solving items for the cooperative classes exceeds the average scores of all the lecture/discussion classes, but again not significantly so at the 95 percent confidence level. The average of the exam scores in the cooperative classes was 81.25 percent, while the average of the lecture/discussion classes was 71.57 percent.

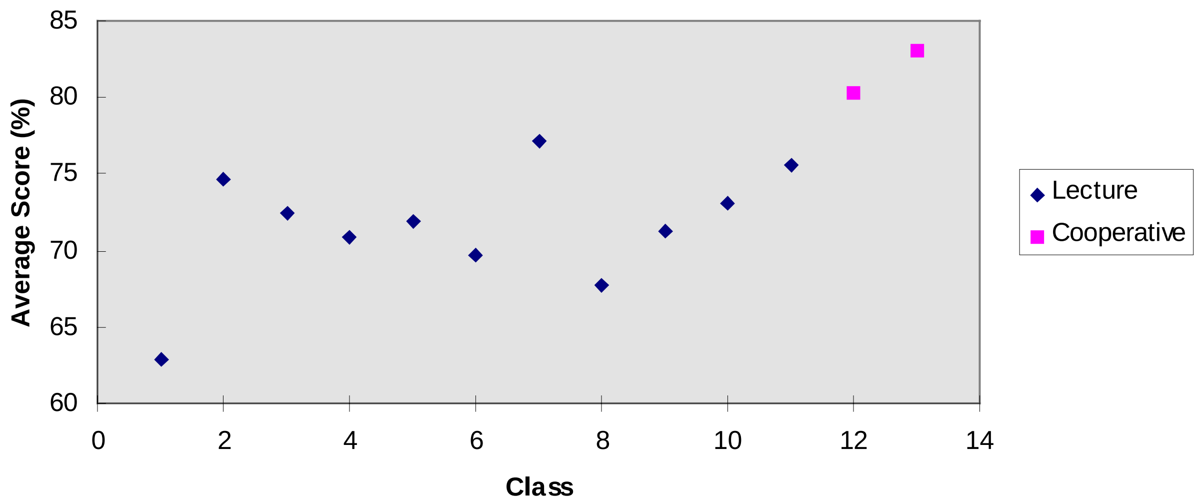

Figure 2 Average Scores on Problem Solving Items

The students felt that the cooperative group format was both more educationally effective and more enjoyable than the lecture/discussion format. Twelve of the 14 students in the two cooperative classes agreed or strongly agreed with the statement that, "The use of the cooperative group exercises in class was more educationally effective than the lecture format used in the first third of the course". The encouragement to work cooperatively on homework assignments had mixed reviews (seven of 14 agreed or strongly agreed that the cooperative homework assignments were more effective than individual assignments). Ten of the 14 students either agreed or strongly agreed that they "enjoyed working in the cooperative groups more than the lecture format", while the remaining students held "no opinion".

The effectiveness of the incentives for the cooperative groups to study together for the unit examination is less certain. In the first cooperative class, seven of the nine students said that they did not work in their cooperative group to prepare for the unit examination. However, four of those seven said they studied with others who were not in their cooperative group. In the second class, the same group structure was used for the cooperative groups as had been used in design groups in a previous course. All of the students in the second class said they studied with their cooperative group to prepare for the examination. These results seem to indicate the importance of preserving pre-existing group structures in the choice of membership of cooperative groups, if cooperative group activities are to be continued outside of class.

As was mentioned in the previous section, there was a considerable lack of enthusiasm for activities oriented to building teamwork skills. Seven of the 14 students either disagreed or strongly disagreed with the statement that, “My group’s work would have been improved if we had spent time developing teamwork skills”, while three students held no opinion. However, there is some evidence that suggests that increased teamwork would have aided at least one of the two groups in the second class. That group did not receive the bonus for group achievement because one member of the group failed to improve his grade on the unit examination. On a number of the items in the examination, the three members of that group had substantially different scores. This suggests that there was probably little communication within the group on a number of key issues that were tested. The most technically capable member of the group was also below average in verbal communication ability, as assessed by the instructor. This group would probably have benefited substantially from an improvement in communication capabilities.

Conclusions and Future Investigations

The investigation of cooperative group strategies for the instruction of neutron diffusion and transport theory is ongoing, but the results achieved to this point have been encouraging. Although, the quantitative results do not support significant differences at the 95 percent confidence level between the lecture/discussion and cooperative strategies, the results support significant differences at nearly a 90 percent confidence interval. This lack of strong statistical support for the findings could be due in part to the small class sizes (to date two classes with a total of 14 students have used the cooperative methods). However, the examination results from both of the cooperative classes exceed the average examination grades of all eleven of the lecture/discussion classes. The results have been particularly encouraging for problem solving items. The quantitative results certainly warrant continued testing of the cooperative approach.

Student attitudes towards the use of cooperative groups have been positive on the whole. Students feel that they learn more from classes and enjoy the classroom experiences more using cooperative group methods than with the lecture/discussion approach. However, there is some apparent resistance to devoting time to developing teamwork skills. A substantial fraction of the graduate students in cooperative sections believed that they already possessed the skills needed to work in cooperative groups. Some development of approaches to present teamwork skills in a manner acceptable to graduate students is needed.

Important questions remain unanswered by the current study. Even if future results indicate that substantial and statistically significant differences do occur when the cooperative strategies are employed, questions concerning the most efficacious elements in the cooperative strategies would remain. Why do cooperative group strategies improve educational outcomes? Increased practice of relevant skills, active learning, or the social interaction itself may all contribute to the success of cooperative strategies. Future studies of cooperative strategies should investigate the relative importance of these factors.

Appendix 1: Rival Hypotheses

The use of one instructor has a significant impact on the validity of the study. The internal validity of the study was improved by using the same instructor for all classes. The presentation of the course by different instructors could have caused significant differences in student achievement due to the idiosyncratic ways that each instructor conducts the course [8]. However, the use of one instructor limits the external validity of the study. The extent to which the results of this study can be generalized to a larger population of instructors is questionable since the only results obtained were from a single instructor.

Two other conditions that might suggest alternative causes for the effects observed in this study were considered. One such rival hypothesis was that an older, more educated student population could have influenced the results observed in favor of the cooperative groups. The subjects of this study were full-time students in an accelerated training program offered at the Bettis Atomic Power Laboratory. The program is similar in level and content to a masters degree program in nuclear engineering. All students entering the program have a baccalaureate degree in engineering, science, or mathematics. Approximately 21 percent of the students held degrees beyond an initial baccalaureate degree in the eleven classes prior to the use of cooperative groups. However, 50 percent of the students had degrees beyond an initial baccalaureate degree in the two classes in which cooperative group methods were implemented. Thus, a rival hypothesis is that the observed results were due to the more accomplished student population. In the cooperative classes, the average grades on the unit examination of students in these two groups (baccalaureate only and baccalaureate and additional degree(s)) differed by 2.7 percent in favor of the students holding additional degrees, a difference that is not statistically significant. However, the average of both groups in the cooperative classes exceeded the average of the students in the classes that used the lecture/discussion format. Adjusting the average score of the cooperative classes for the differences in educational attainment between the baccalaureate only and additional degree groups would result in an approximately 0.8% decrement in the average score of the cooperative classes. Thus, level of education apparently has too small an effect to account for the observed differences in average test scores. Further consideration will be given to this effect as the results are available from a larger sample of the student population.

Another rival hypothesis concerned the validity of the measuring instrument. Because of the small number of available students, the results of the cooperative groups were compared with the historical results of traditional groups (instead of randomly forming a control group). The questions on the unit examination used in the testing of the cooperative group students were not drawn randomly from a pool of questions from which the traditional groups were tested. Similarly, the tests given the traditional groups were not constructed randomly. Thus, a random construction of the cooperative tests would have been inconsistent with prior test construction methods. Instead, a test given previously to one particular traditional class was used to test the cooperative groups. The particular test chosen was selected because the traditional class had scored closest to the historical mean of all traditional classes (between 0.2 and 0.3 percent above the mean). An alternative hypothesis might be that the chosen test was not representative of the tests given to most of the traditional groups. However, many of the items used on the chosen test were similar to items used on other examinations without any indications of biases. Further, the traditional students examined with the chosen test also performed close to the historical average on other tests given in the course. The test appears to provide a reasonably valid comparison between traditional and cooperative group achievement.

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