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COOPERATIVE LEARNING IN TECHNICAL COURSES: PROCEDURES, PITFALLS, AND PAYOFFS

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FOREWORD

A longitudinal study of a cohort of engineering students has been under way at North Carolina State University since 1990. Dr. Richard Felder taught the students five chemical engineering courses in five consecutive semesters using several nontraditional instructional methods, including cooperative (team-based) learning. The performance of the students in these courses and their responses to the instruction have been chronicled elsewhere (Felder *et al.,* 1993, 1994a, 1994b).

As part of the longitudinal study, Dr. Felder and Dr. Rebecca Brent, a professor of education at East Carolina University, adapted or devised procedures for implementing cooperative learning in courses that stress quantitative problem solving. These procedures are summarized in this report. The objectives of the report are to offer some ideas for using cooperative learning effectively in technical courses, to give advance warning of the problems that might arise when CL is implemented, and to provide assurances that the eventual benefits to both instructors and students amply justify the perseverance required to confront and overcome the problems.

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INTRODUCTION: ELEMENTS OF COOPERATIVE LEARNING

Cooperative learning (CL) is instruction that involves students working in teams to accomplish a common goal, under conditions that include the following elements (Johnson, Johnson, and Smith, 1991):

1. **Positive interdependence.** Team members are obliged to rely on one another to achieve the goal. If any team members fail to do their part, everyone suffers consequences.

2. **Individual accountability.** All students in a group are held accountable for doing their share of the work and for mastery of all of the material to be learned.

3. **Face-to-face promotive interaction.** Although some of the group work may be parcelled out and done individually, some must be done interactively, with group members providing one another with feedback, challenging one another's conclusions and reasoning, and perhaps most importantly, teaching and encouraging one another.

4. **Appropriate use of collaborative skills.** Students are encouraged and helped to develop and practice trust-building, leadership, decision-making, communication, and conflict management skills.

5. **Group processing.** Team members set group goals, periodically assess what they are doing well as a team, and identify changes they will make to function more effectively in the future.

Cooperative learning is not simply a synonym for students working in groups. A learning exercise only qualifies as CL to the extent that the listed elements are present.

Cooperative learning may occur in or out of class. In-class exercises, which may take anywhere from 30 seconds to an entire class period, may involve answering or generating questions, explaining observations, working through derivations, solving problems, summarizing lecture material, trouble-shooting, and brainstorming. Out-of-class activities include carrying out experiments or research studies, completing problem sets or design projects, writing reports, and preparing class presentations.

A large and rapidly growing body of research confirms the effectiveness of cooperative learning in higher education (Astin, 1993; Cooper *et al.,* 1990; Goodsell et al., 1992; Johnson *et al.,* 1991; McKeachie, 1986). Relative to students taught traditionally - i.e., with instructor-centered lectures, individual assignments, and competitive grading - cooperatively taught students tend to exhibit higher academic achievement, greater persistence through graduation, better high-level reasoning and critical thinking skills, deeper understanding of learned material, more on-task and less disruptive behavior in class, lower levels of anxiety and stress, greater intrinsic motivation to learn and achieve, greater ability to view situations from others' perspectives, more positive and supportive relationships with peers, more positive attitudes toward subject areas, and higher self-esteem. Another nontrivial benefit for instructors is that when assignments are done cooperatively, the number of papers to grade decreases by a factor of three or four.

There are several reasons why cooperative learning works as well as it does. The idea that students learn more by doing something active than by simply watching and listening has long been known to both cognitive psychologists and effective teachers (Bonwell and Eison, 1991), and cooperative learning is by its nature an active method. Beyond that, cooperation enhances learning in several ways. Weak students working individually are likely to give up when they get stuck; working cooperatively, they keep going. Strong students faced with the task of explaining and clarifying material to weaker students often find gaps in their own understanding and fill them in. Students working alone may tend to delay completing assignments or skip them altogether, but when they know that others are counting on them, they are often driven to do the work in a timely manner. Students working competitively have incentives not to help one another; working cooperatively, they are rewarded for helping.

The proven benefits of cooperative learning notwithstanding, instructors who attempt it frequently encounter resistance and sometimes open hostility from the students. Bright students complain about begin held back by their slower teammates, weaker or less assertive students complain about being discounted or ignored in group sessions, and resentments build when some team members fail to pull their weight. Instructors with sufficient patience generally find ways to deal with these problems, but others become discouraged and revert to the traditional teacher-centered instructional paradigm, which is a loss both for them and for their students.

In this paper we outline several cooperative learning exercises that have worked particularly well for us in engineering courses. We then suggest ways to maximize the benefits of the approach and to deal with the difficulties that may arise when CL is implemented. The primary sources for the material to be presented are Johnson, Johnson, and Smith (1991) and our personal experience.

IN-CLASS EXERCISES

Early in a class period, organize the students (or have them organize themselves) into teams of two to four students, and randomly assign one student in each group (e.g. the youngest one or the one with the darkest hair or the one whose home town is farthest away from campus, or the student to the right of the one in the selected category) to be the team recorder for that class period. Several times during the period - ideally, after no more than 15 minutes of lecturing - give the teams exercises to do, instructing the recorders to write down the team responses. In longer exercises, circulate among the teams, verifying that they are on task, everyone is participating, and that the recorders are doing their job. Stop the teams after a suitable period has elapsed (which may be as short as 30 seconds or as long as 10 minutes, depending on the exercise) and randomly call on students to present their teams' solutions. The exercises can range from short questions to extensive problem-solving activities in a variety of categories.

- **Recalling prior material**
  Last period we discussed conductive heat transfer. List as many of the principal features of this process as you can remember. You have two minutes - go! List the three most important points in today's assigned reading.

- **Stage-setting**
  Here are some questions we'll be considering today. Work in pairs to guess (estimate) what the answers might be (to plan how you could determine the answers).

Asking the students to think in advance about the questions can effectively motivate them to watch for the answers in the rest of the class period.

- **Responding to questions.**
  What procedure (formula, technique) could I use here?
  Is what I just wrote correct? Why or why not?
  What action might I take in the situation just described?
  What would you guess is the next step (the outcome, the conclusion)?

This approach to classroom questioning offers several advantages over more conventional methods. Asking questions of the class as a whole usually produces either an embarrassing silence (especially in large classes) or answers volunteered by two or three students - the same students every time. Calling on students individually often creates an atmosphere of tension in the classroom, with many students worrying more about whether you will single them out than about what you are teaching. On the other hand, when students are asked to generate answers in small groups, most of them will get right to work without feeling threatened and you'll get all the responses you want.

- **Problem-solving**
  Turn to page 138 in your textbook. Take a minute to read Problem 27, then work in your groups to outline a solution strategy.

  Without doing any detailed analysis (calculations), guess what the solution of the problem might be, and justify your guess.

Get started on the solution of the problem and see how far you can get with it in five minutes.

Let's all agree that this is the correct approach. Proceed from here.

...and so this is the solution we get. Find at least two ways to check it.

Suppose we observe a real system of the kind we just analyzed and our observations don't match our results. List possible reasons.

The groups should generally be given enough time to think about the problem and to begin to formulate an answer but not necessarily enough to work through to a complete solution.

- **Explaining written material**. Exercises of this type are effectively done in pairs.

  Go through the paragraph (derivation) I just handed out. One member of each pair should explain each idea (step) to the other. The explainer's partner should ask for clarification if anything is unclear and may give general hints if needed but should not take over the job of explaining. Raise your hands if you get stuck.

  Partner 1, describe to your partner one of the terms from the reading listed on the board. Partner 2, try to identify the term being described.

Have the students work for several minutes in this way, stop them, call on one or more pairs to summarize their work, and then have the students continue with the roles reversed.

If you assign students to read complex material on their own, many or most will not do it, and if you write it on the board, they will copy it into their notes without necessarily understanding or even thinking about it. If you require them to explain it to one another, however, they will either work through it and achieve understanding or get stuck and be primed to hear the explanation when it is presented.

- **Analytical, evaluative, and creative thinking**

  List all the (assumptions, problems, errors, ethical dilemmas) you can find in this case study (scenario,problem solution)

  Explain in terms a bright high school senior could understand the concept of (surface tension, relative humidity, discounted cash flow rate of return on investment).

  Construct a concept map (flow chart, graphic organizer) containing the principal topics in Chapter 5 of your text.

  Predict what would happen if you carried out the following experiment. Explain your reasoning.

  What is the flaw in the following argument?

  Explain, in terms of concepts you learned in this course, why you feel comfortable in 65 deg.F air and freezing in 65 deg.F water.

  List three practical applications for what we just learned.

Think of as many reasons as you can why this design (theory, model, strategy) might (fail, be unsafe, be environmentally unsound).

Which of the following alternative (sentences, explanations, devices) is the best one? Justify your answer.

You might also pose problems that are incompletely defined and require estimations or assumptions to be solved. Felder has asked a chemical engineering class to estimate the rate of heat input to a teakettle on a stove burner turned to its maximum setting. To get the solution, the students have to apply standard engineering calculations but they must also estimate the volume of a typical kettle and the time it takes to heat a kettle to boiling, estimations that are not included in the problem statement. Working on such problems trains students to exercise higher-level thinking skills and prepares them to engage in similar thinking on homework assignments and tests.

- **Generating questions and summarizing**

Think of three good questions about what we just covered. Then see how far you can go in answering them.

List the major point in the material we covered today. Then list the muddiest point.

The collective response to the latter exercise provides the instructor with a clear indication of how well the class worked that day and what points should be addressed at the beginning of the next period.

Alison King (1993) uses an exercise she calls **guided reciprocal peer questioning,** which consists of giving students high-level question stems and having them use these stems to construct specific questions on the course material, which they then ask their classmates. Some of these generic stems are

"What is the main idea of...?"
"What if...?"
"How does...affect...?"
"What is the meaning of...?"
"Why is...important?"
"What is a new example of...?"
"Explain why...."
"Explain how...."
"How does...relate to what I've learned before?"
"What conclusions can I draw about...?
"What is the difference between ... and ...?"
"How are ... and ... similar?"
"How would I use ... to ...?"
"What are the strengths and weaknesses of...?"

King finds that repeated use of these exercises leads to a noticeable improvement in the higher level thinking abilities of her students.

An effective variation of the in-class group exercise is **think-pair-share**. Students first work on a given problem individually, then compare their answers with a partner and synthesize a joint solution. The pairs may in turn share their solutions with other pairs or with the whole class. Another variation that has already been described is **TAPPS**--thinking-aloud pair problem-solving (Lochhead and Whimbey, 1987). Students work on problems in pairs, with one pair member functioning as problem-solver and the other as listener. The problem solvers verbalize everything they are thinking as they seek a solution; the listeners encourage their partners to keep talking and offer general suggestions or hints if the problem solvers get stuck. The roles are reversed for the next problem.

Still another in-class strategy, **Jigsaw** (Aronson, 1978), is excellent for tasks that have several distinct aspects or components. Home teams are formed, with each team member taking responsibility for one aspect of the problem in question. Expert teams are then formed of all the students responsible for the same aspect. The teams go over the material they are responsible for and plan how to best teach it to their home groups. After adequate time has been given, the students return to the home teams and bring their expertise to bear on the assigned task. Positive interdependence is fostered because each student has different information needed to complete the task.

Besides their pedagogical benefits, in-class cooperative exercises make classes much more enjoyable for both students and instructors. Even the most gifted lecturers have trouble sustaining attention and interest throughout a 50-minute class: after about ten minutes, the attention of the students starts to drift, and by the end of the class boredom is generally rampant. Even if the instructor asks questions in an effort to spark some interest, nothing much usually happens except silence and avoidance of eye contact. A well-known study of information retention supports this picture of what happens: immediately after a lecture, students were found to recall about 70% of the content presented during the first ten minutes and 20% of the content of the last ten minutes (Hartley and Davies, 1978).

When group exercises are interspersed throughout a lecture, the picture changes. Once a class accustomed to group work gets going on a problem, the classroom atmosphere changes: the leaden silence changes to a hum, then a chatter, punctuated by arguments and laughter. Most students - even those not doing much talking - are engaged in thinking about the question at hand instead of just mechanically transcribing notes from the chalkboard. Even if some students refuse to participate, as they might, an active involvement of 90-95% is clearly superior to the 5-10% or less that characterizes most lectures.

OUT-OF-CLASS EXERCISES

Research and design projects, laboratory experiments, and homework problem sets can all be effectively completed by teams of students. The teams may function as *formal cooperative learning groups*, remaining together until the completion of an assignment and then disbanding, or as *cooperative base groups*, remaining together for an entire course or even longer (Johnson *et al.*, 1991). The periodic reforming of formal cooperative learning groups exposes the students to a larger variety of learning styles and problem-solving approaches than they would see in base groups; the base groups tend to provide more assistance and encouragement to their members. (A third category, *informal cooperative learning groups*, refers to teams that come together and disperse within a single class period, as in the exercises listed previously.)

Following are several suggestions for setting up CL groups and structuring assignments:

- *Give assignments to teams of three or four students.* When students work in pairs, one of them tends to dominate and there is usually no good mechanism for resolving disputes, and in teams of five or more it becomes difficult to keep everyone involved in the process. Collect one assignment per group.

- *Try to form groups that are heterogeneous in ability level.* The drawbacks of a group with only weak students are obvious, but having only strong students in a group is equally undesirable. First, the strong groups have an unfair advantage over other groups in the class. Second, the team members tend to divide up the homework and communicate only cursorily with one another, omitting the dynamic interactions that lead to most of the proven benefits of cooperative learning. In mixed ability groups, on the other hand, the weaker students gain from seeing how better students study and approach problems, and the stronger students gain a deeper understanding of the subject by teaching it to others (a phenomenon familiar to every teacher).

- *Avoid groups in which women and minority students are outnumbered*. Studies have shown that women's ideas and contributions are often devalued or discounted in mixed gender teams, and the women end by taking passive roles in group interactions, to their detriment (Felder *et al.,* 1994b; Heller and Hollabaugh, 1992). Groups containing all men, two women and one or two men, or all women are acceptable, but one woman and two or three men should be avoided. The same rule applies to minority students.

- *If at all possible, select the teams yourself*. In one study, 155 students surveyed claimed in a 2/1 ratio that their worst group work experiences were with self-formed groups and their best ones were with instructor-formed groups (Feichtner and Davis, 1991). Other studies in the CL literature generally support this finding.

On the first day of class, we have the students fill out a questionnaire indicating their sex, ethnicity, and either overall GPA or grades in selected prerequisite courses. (Students who do not wish to provide this information are free to withhold it, but few do.) We use the collected questionnaires to form the groups, following the guidelines given above. We have also occasionally let students self-select into groups, stipulating that no group may have more than one student who earned A's in specified courses and strongly recommending that women and minority students avoid groups in which they are outnumbered. While not perfect, this system at least assures that the very best students in the class do not cluster together, leaving the weaker ones to fend for themselves.

A problem may arise if assignments require long periods of time out of class and many students live off campus and/or have outside jobs. Instructor-formed groups may then find it almost impossible to agree on a suitable meeting time and place. We have shuffled groups to allow commuters to work together to the extent that they can, recognizing that they will lose some of the benefits of CL by not having as much face-to-face interaction as the other students in the class.

- *Assign team roles that rotate with each assignment*. Johnson *et al*. (1991) suggest (1) the *coordinator* (organizes assignment into subtasks, allocates responsibilities, keeps group on task), (2) the *checker* (monitors both the solutions and every team member's comprehension of them), and (3) the *recorder* (checks for consensus, writes the final group solution). Heller *et al.* (1992) propose (4) the *skeptic* (plays devil's advocate, suggests alternative possibilities, keeps group from leaping to premature conclusions). Only the names of the students who actually participated should appear on the final product, with their team roles for that assignment identified.

- *Promote positive interdependence.* All team members should feel that they have unique roles to play within the group and that the task can only be completed successfully if all members do their parts. Strategies to achieve this objective include the following:

    1. *Require a single group product.*
    2. *Assign rotating group roles.*
    3. *Give each member different critical resources, as in Jigsaw.*
    4. *Select one member of each group to explain (in an oral report or a written test) both the team's results and the methods used to achieve them, and give every team member the grade earned by that individual.* Avoid selecting the strongest students in the groups.
    5. *Give bonuses on tests to groups for which the lowest team grade or the average team grade exceeds a specified minimum.*

    The last two strategies provide powerful incentives for the stronger team members to make sure that the weaker ones understand the assignment solution and the material to be covered on the test.

- *Promote individual accountability.* The most common way to achieve this goal is to give primarily individual tests; another is the technique mentioned above of selecting an individual team member to present or explain the team's results. Some authors suggest having each team member rate everyone's effort as a percentage of the total team effort on an assignment and using the results to identify noncontributors and possibly to adjust individual assignment grades; others recommend against this procedure on the grounds that it moves the team away from cooperation and back toward competition. We occasionally use it, but only in classes in which students have repeatedly expressed complaints about irresponsible team members.

- *Have groups regularly assess their performance.* Especially in early assignments, require them to discuss what worked well, what difficulties arose, and what each member could do to make things work better next time. The conclusions should be handed in with the final group report or solution set, a requirement that motivates the students to take the exercise more seriously than they otherwise might.

- *Offer ideas for effective group functioning*. Working effectively in teams is not something people are born knowing how to do, nor is it a skill routinely taught in school. Quite the contrary, in fact: as Bellamy *et al.* (1994) observe, working together in college courses is more likely to be regarded as cheating and punished than viewed positively and encouraged. The same authors note that "The traditional approach to team building in academe is to put three to five students together and to let them 'work it out' on their way to solving a problem. A better approach is to prepare the students with some instructional elements that will generate an appreciation of what teaming (as opposed to just working in groups) involves, and to foster the development of interpersonal skills that aid in team building and performance."

  Some elements of effective group functioning are relatively self-explanatory and might be given to teams as a check list. These elements include showing up for meetings on time, avoiding personal criticisms, making sure everyone gets a chance to offer ideas, and giving those ideas serious consideration. Other recommendations we make to homework teams working on quantitative problems are these:

  1. *Set up all assigned problems individually (no detailed mathematical or numerical calculations), then meet as a group to put the complete solution set together*. We tell the students that if they simply parcel out the work, each of them will understand their own part but not the others, and their lack of understanding will hurt them on the individual tests. On the other hand, if they only work as a complete group, certain quick-thinking students will tend to begin every problem solution, which will put their teammates at a disadvantage on the tests.

  2. *Don't allow a situation to develop in which one or two students work all the solutions out and then quickly explain them to teammates who didn't really participate in obtaining them. If this happens no one is getting the full benefits of cooperative learning, and the explainees will probably crash and burn on the tests.* (This message may not get through to some students until after the first test.)

  3. *Don't put someone's name on the solution set if they did not participate in generating the set, especially if it happens more than once*. We don't like using test threats, (as in Items 1 and 2) to goad students into following good teamwork practices, but we have never found another motivator as effective for most engineering students, especially in their first and second years.

- *Provide assistance to teams having difficulty working together.* Teams with problems should be invited or required to meet with the instructor to discuss possible solutions. The instructor should facilitate the discussion and may suggest alternatives but should not impose solutions on the team.

  We allow teams to fire noncooperative team members if every other option has failed, and we also allow individuals to quit if they are doing most or all of the work and team counseling has failed to yield improvements. Fired team members or members who quit must then find other teams willing to accept them. In our experience, just the knowledge that this option is available usually induces noncooperative team members to change their ways; in chemical engineering classes containing as many as 50 teams, rarely does more than one team dissolve in the course of a semester.

- *Don't reconstitute groups too often*. A major goal of cooperative learning is to help students expand their repertoire of problem-solving approaches, and a second goal is to help them develop collaborative skills - leadership, decision-making, communication, etc. These goals can only be achieved if students have enough time to develop a group dynamic, encountering and overcoming difficulties in working together. Cooperative groups should remain together for at least a month for the dynamic to have a chance of developing.

- *DON'T ASSIGN COURSE GRADES ON A CURVE.* The only way cooperative learning will work is if students are given every incentive to help one another. If students are guaranteed a given grade if they meet a specified standard (e.g. a weighted average grade of 90 or better for an A), they have everything to gain and nothing to lose by cooperating; if they know that by helping someone else they could be hurting themselves (as is the case when grades are curved), cooperation is finished.

  Felder uses a grading system in engineering courses that gets away from curving but also avoids the inflexibility of strict numerical criteria (90 is an A, 89 is a B, no exceptions). Students are guaranteed A's if they get weighted average grades of 90 or higher, B's with 80 or higher, C's with 70 or higher, and D's with 60 or higher. In addition, there are "gray areas" extending several points below these criterion grades. Students whose weighted average grades fall in these ranges may get the next higher letter grade in the course if they have done satisfactory work on a specified number of extra-credit challenge problems and/or their test grades have been steadily improving. This policy is announced in writing on the first day of the course and has never led to complaints about unfairness.

CASE STUDY: COOPERATIVE LEARNING IN A SEQUENCE OF CHEMICAL ENGINEERING COURSES

This section presents a case history of cooperative learning in a a sequence of chemical engineering courses that Felder taught in successive semesters to roughly the same body of students. Five semester-long courses constituted the experimental sequence:

1. *CHE 205 - Chemical Process Principles* (Fall 1990 - 4 credits). Material and energy balances on chemical processes, basic concepts and calculations.
2. *CHE 225 - Chemical Process Systems* (Spring 1991 - 3 credits). Process variable measurement methods, computer simulation of processes, applied statistical analysis.
3. *CHE 311 - Transport Processes I* (Fall 1991 - 3 credits). Fluid dynamics and heat transfer.
4. *CHE 312 - Transport Processes II* (Spring 1992 - 3 credits). Mass transfer and separation processes.
5. *CHE 446 - Chemical Reactor Design and Analysis* (Fall 1992 - 3 credits).

The basis for the instructional approach used in all five courses was the cooperative learning model articulated by Johnson, Johnson, and Smith (1991), with most deviations from their recommendations being due primarily to the instructor's inexperience and/or timidity. Homework assignments were done by fixed teams of three or four students that with few exceptions remained together for an entire semester, and in-class exercises were done by groups of two to four students that changed from one class period to another. A chronology of the study follows, narrated by Felder.

First day of CHE 205. I announced that all homework must be done in fixed groups with one solution set handed in per group, gave the criteria for group formation (three or four members, no more than one of whom could have received A's in specified mathematics and physics courses), and specified individual roles within groups (coordinator, recorder, and one or two checkers, with the roles rotating on each assignment).

I spent some time explaining why I was doing all this, assuring the students that it wasn't just a game I was playing with them or something I designed to make my life easier (quite the contrary). I told them that both educational research and my experience indicated that students learn better and get higher grades by teaching one another some of the time rather than listening to professors lecture all of the time. I also guaranteed them that when they went to work as engineers they would be expected to work in teams, so they might as well start learning how to do it now. During the next two days, several students expressed strong reservations about group work and requested permission to work alone. Permission was denied.

Second day of CHE 205. I interspersed small group problem-solving exercises throughout my lecture. The student response was variable - the level of interaction generally decreased with distance from the front of the room. At the end of the period, I asked students who had not yet affiliated with homework teams to get together after class with teams of three willing to pick up a fourth member and work things out, which they did.

First homework assignment. Assignments were turned in by most students working in groups as instructed, but also by several individuals and one "group" consisting of the student, Elvis Presley, and Richard M. Nixon. I applauded that student for creativity but informed all those who had not yet joined a group that the fun was over and I would accept no further assignments from individuals. By the due date of the second assignment, all students were in homework groups.

First three weeks. I continued to use in-class group exercises, generally taking about ten minutes of every 50-minute period, and occasionally beginning the period by telling the students to sit somewhere new and work with people they had not worked with before. I varied the exercises, using a mixture of problem-solving, think-pair-share, trouble-shooting, brainstorming, and question generation, so that the students never knew what was coming from one class to the next. The level of active student involvement continually increased, leveling out at 90-100%.

Occasionally in class I offered suggestions for effective homework team functioning, trying not to be too preachy about it. A recommendation I made on several occasions was for the students to set up all problem solutions individually, then work together to complete the problem set. I occasionally got complaints in my office about team members not pulling their weight or missing group sessions, or about personal conflicts between group members, and I met with several groups in my office during the semester to help them work out solutions. (In the end, only one group actually dissolved out of roughly 35 in the class.)

Dropouts during this period brought some groups down to two members. Some pairs combined, others disbanded and individually joined teams of three. (In subsequent courses, I allowed some pairs to remain intact if dropouts occurred late in the semester.)

End of four weeks. The class average on the first test was 66, brought down by some very low grades (as low as 10). Some students complained that the better members of their groups had been working out most of the homework solutions and the complaining students were consequently hurt on the test. I announced in class that students doing all the work in their teams were hurting their classmates rather than helping them, and I repeated the message about setting up problems individually and completing them in groups. The students who had complained soon afterward reported improved interactions within their groups.

End of six weeks. Midsemester evaluations were overwhelmingly positive about group work. I announced that students who wished to do so could now do homework individually. Out of roughly 115 students remaining in the course, only three elected to do so, two of whom were off-campus students who were finding it difficult to attend group work sessions. In courses I taught subsequently, I occasionally assigned individual homework but never again let the students opt out of assigned group work.

Last half of CHE 205. The student lounge began to resemble an ant colony the day before an assignment was due - small groups clustered everywhere, occasionally sending out emissaries to other groups to compare notes and exchange hints (which I permitted as long as entire solutions were not exchanged). The nature of my office hours changed considerably from the start of the semester, with fewer individual students coming in to ask "How do you do Problem 3" and more groups coming in for help in resolving debates about open-ended problems. I inferred with considerable satisfaction that the students had begun to count on one another to resolve straightforward questions instead of looking to me as the source of all wisdom.

The final grade distribution in CHE 205 was dramatically different from any I had ever seen when I taught this course before. In the previous offerings, the distribution was reasonably bell-shaped, with more students earning C's than any other grade. When the course was taught cooperatively, the number of failures was comparable to the number in previous offerings but the overall distribution was markedly skewed toward higher grades: 26 A's, 40 B's, 15 C's, 11 D's, and 26 F's. Many of those who failed had quit before the end of the course. The course evaluations were exceptionally high and most students made strong statements about how much the group work improved their understanding of the course material. My conclusion was that CL led to improved learning in all but the least qualified and most poorly motivated students.

Remaining courses. At my encouragement, new teams formed at the beginning of each semester, even when all members of a team from the previous semester remained in the sequence. I continued to ask the teams to assess their performance periodically and to meet with me if they had persistent problems. The students' level of comfort with cooperative learning continually increased, although there were always problems that needed attention. No more than two teams in any semester had recourse to the last resort options of firing or quitting.

I observed a greater sense of community in this cohort of students by the time they were juniors than I had seen in any other chemical engineering class. They studied together, partied together, and displayed a remarkable sense of unanimity in complaining about things in the chemical engineering program that they didn't like. One student commented, "This class is different from any I've been in before. Usually you just end up knowing a couple of people - here I know everyone in the class. Working in groups does this."

Several times during the experimental course sequence the students were asked to rate how helpful cooperative learning was to them. Their ratings of group homework were consistently and overwhelmingly positive. At the midpoints of the introductory sophomore course, the two junior courses, and the senior course, the percentages rating CL above average in helpfulness were respectively 83%, 85%, 87%, and 86%, and the percentages rating it below average were 9%, 7%, 7%, and 7%. The ratings of in-class group exercises were also positive, but it took many of the students longer to appreciate the benefits of these exercises. Above average ratings were given by 41%, 70%, and 86% of the respondents in the two junior courses and the senior course, and below average ratings were given by 24%, 12%, and 6%, respectively. (The question was unfortunately omitted in the sophomore course survey.)

In the semester following the experimental course sequence, the students were asked to evaluate the sequence retrospectively. Of 67 seniors responding, 92% rated the experimental courses more instructive than their other chemical engineering courses, 8% rated them equally instructive, and none rated them less instructive. Sixty percent considered the experimental courses very important factors in their decision to remain in chemical engineering, 28% considered them important, and 12% rated them not very important or unimportant. Ninety-eight percent rated group homework helpful and 2% rated it not helpful, and 78% rated in-class group work helpful and 22% rated it not helpful.

One episode in particular led me to believe that group work was having the desired effect on the quality of the students' learning. In the third semester of the study, the class was taking fluid dynamics and heat transfer with me and thermodynamics with a colleague. My colleague is a traditional instructor, relying entirely on lecturing to impart the course material, and he is known for his long and difficult tests, with averages in the 50's or even less not unheard of. The average on his first test that semester was 72, and that on the second test was 78, and he ended by concluding that it was perhaps the strongest class he had ever taught. Meanwhile, I casually asked the students how things were going, mentioning that I heard they were doing well in thermo. Several of them independently told me that they had become so used to working in groups, meeting before my tests, speculating on what I might be likely to ask, and figuring out how they would respond, that they just kept doing it in their other classes - and it worked! To my way of thinking, cooperative learning had achieved its intended effect.

ISSUES AND ANSWERS

We regularly teach about cooperative learning in faculty development workshops and find that the participants fall into two broad categories. On the one hand are the skeptics, who creatively come up with all sorts of reasons why CL could not possibly work for their subjects and their students. On the other hand are the enthusiasts, who are sold by our descriptions of the method and its benefits and set out to implement CL fully in their very next class. We know all the reservations about cooperative learning, having once had them all ourselves, and we can usually satisfy most of the skeptics that the problems they anticipate may not occur, and if they occur they are solvable. We worry more about the enthusiasts. Despite our best efforts, they often charge off and simply turn students loose in groups, imagining they will immediately see the improved performance and positive attitudes that the CL literature promises them.

The reality may be quite different. Many students - especially bright ones - begin with a strong resistance or outright hostility to working in teams, and they may be quite vocal on the subject when told they have no choice. Moreover, interpersonal conflicts - usually having to do with differences among team members in ability, work ethic, or sense of responsibility - inevitably arise in group work and can seriously interfere with the embattled group's morale and effectiveness. Instructors unexpectedly confronted by these problems might easily conclude that CL is more trouble than it is worth.

As with so much else in life, however, in cooperative learning forewarned is forearmed. The paragraphs that follow itemize common concerns about CL and our responses to them.

- *If I spend all this time in class on group exercises, I'll never get through the syllabus.*

  You don't have to spend that much time on in-class group work to be effective with it. Simply take some of the questions you would normally ask the whole class in your lecture and pose them to groups instead, giving them as little as 30 seconds to come up with answers. One or two such exercises that take a total of five minutes can keep a class relatively attentive for an entire 50-minute period.

  On a broader note, covering the syllabus does not mean that teaching has been successful: what matters is how much of the material covered was actually learned. Students learn by doing, not by watching and listening. Instead of presenting all the course material explicitly in lectures, try putting explanatory paragraphs, diagrams, and detailed derivations in handouts, leaving gaps to be filled in during class or by the students on their own time. (If you announce that some of the gaps will be the subject of test questions and then keep your promise, the students *will* read the handouts.) You can then devote the hours of board-writing time you save to active learning exercises, your classes will be more lively and will lead to more learning - and you will still cover the syllabus.

- *If I don't lecture I'll lose control of the class.*

  That's one way to look at it. Another is that several times during a class period your students may become heavily involved in discussing, problem solving, and struggling to understand what you're trying to get them to learn, and you may have to work for a few seconds to bring their attention back to you. There are worse problems.

- *If I assign homework in groups, some students will "hitchhike,"* getting credit for work in which they did not actively participate.

  This is always a danger, although students determined to get a free ride will usually find a way, whether the assignments are done individually or in groups. In fact, cooperative learning that includes provisions to assure individual accountability cuts down on hitchhiking. Students who don't actually participate in problem-solving will generally fail the individual tests, especially if the assignments are challenging (as they always should be if they are assigned to groups) and the tests truly reflect the skills involved in the assignments. If the group work only counts for a fraction of the overall course grade (say, 10-20%), hitchhikers can get high marks on the homework and still fail the course.

  A technique to assure active involvement by all team members is to call randomly on individual students to present solutions to group problems, with everyone in the group getting a grade based on the selected student's response. The technique is particularly effective if the instructor tends to avoid calling on the best students, who then make it their business to make sure that their teammates all understand the solutions. Another approach is to have all team members anonymously evaluate every member's level of participation on an assignment (e.g. as a percentage of the total team effort). These evaluations usually reveal hitchhikers. Students want to be nice to one another and so they may agree to put names on assignments of teammates who barely participated, but they are less likely to credit them with high levels of participation.

- *Groups working together on homework assignments may rely on one or two people to get all the problem solutions started. The others may then have difficulties on individual tests when they must begin the solutions themselves.*

  This is a legitimate problem. An effective way to avoid it is for each group member to set up and outline each problem solution individually, and then for the group to work together to obtain the complete solutions. If the students are instructed in this strategy and are periodically reminded of it, some or all of them will discover its effectiveness and adopt it. There is also merit in assigning some individual homework problems to give the students practice in the problem-solving mode they will encounter on the tests.

- *I have had major problems with groups not working together well or not getting along at all.*

  This often happens with group work in any academic or professional setting. When students come to you complaining about some group member dominating or never showing up or about their having to carry most of the load themselves, you might begin by welcoming them to the real world. Point out that they will probably spend a good part of their professional careers working with others, some of whom they won't care for, and suggest that this is a good time to start learning how to do it.

Then propose corrective measures. If you have not previously required team assessment of the group process as part of some or all assignments, do it now, with the groups having problems or (preferably) with all groups. Sometimes students find it easier to complain to you than to discuss problem situations frankly with one another. In the course of assessing what's not working well in the group, the students may also figure out how to correct the problems before they ever get to you. You may invite them to have an assessment session in your office, and if they do, try to steer the discussion in constructive directions.

You may allow teams the option of firing noncooperative members after giving them at least two warnings and allow individuals carrying most of the workload the option of joining another group after giving their noncooperative teammates at least two warnings. In our experience, these options will rarely be exercised: teams almost invariably find ways of working things out before it comes to that.

- *When I tried cooperative learning in one of my classes many of the students hated it - they wouldn't cooperate, complained constantly and bitterly, and gave me terrible ratings at the end of the course.*

  As we observed before, instructors who set out to try cooperative learning in a class for the first time are sometimes unpleasantly surprised by the students' response. Instead of plunging eagerly into group work and immediately exhibiting the promised learning gains and development of social skills, these students view the approach as some kind of game the instructor is playing with them, and some become sullen or hostile when they find they have no choice about participating. They may complain that they work better alone, or that they don't want to be held back by weaker students. Confronted with group exercises during class, some may grouse that they are paying tuition - or their parents are paying taxes - to be taught, not to teach themselves.

  Instructors who don't anticipate a negative reaction from some students when they try CL for the first time can easily get discouraged when they encounter it and are likely to abandon the approach rather than trying to get past the resistance. It is not sufficient simply to put the students in groups and hope that they will immediately see the benefits; they must be persuaded that cooperative learning is not something you are doing on a whim or as an educational experiment, but a proven approach that has been repeatedly shown to work in students' interests.

  Before you do in-class group work for the first time, announce that you plan on using such exercises regularly during the class because research shows that students learn by doing, not by watching and listening. You can reinforce your point by adding one or more of the following observations:

  - *You have had the experience of sitting through a well-organized and well-delivered lecture, believing that you understood it, but then later when you tried to do the homework you realized that you didn't understand the lecture at all. By working actively for brief periods in class, you're getting a head start on the homework by starting to understand the lecture while it's going on.*

- *Even the most dedicated students can't stay focused on a lecture for more than about 10 minutes, and most can't go that long. Your attention starts to drift, first for short periods, then for longer ones. By the end of a 50-minute period, you are likely to hear and remember less than 20% of the content. Short group exercises during a lecture cut down on boredom and increase the amount of the lecture that you'll actually hear.*
- (To students complaining about being slowed down by having to explain material they understand to slower teammates.) *If you ask any professor, "When did you really learn thermodynamics (or structural analysis or medieval history)?" the answer will almost always be "When I had to teach it. "Suppose you are trying to explain something, and your partner doesn't get it. You may try to explain it in a different way, and then think of an example, and then perhaps find an analogy to something familiar. After a few minutes of this your partner may still not get it, but you sure will.*

In our experience, most students bright enough to complain about being held back by their classmates are also bright enough to recognize the truth of the last argument. We also point out that most students will eventually have jobs that require them to work in teams, and that learning how to do so is an important part of their professional training.

Perhaps the most effective selling point (unfortunately) involves grades. Many research studies have demonstrated that students who learn cooperatively get higher grades than students who try to learn the same material individually. Before assigning group work for the first time, Felder mentions a study by Pete Tschumi of the University of Arkansas at Little Rock (Tschumi, 1991). Tschumi taught an introductory computer science course three times, once with the students working individually and twice using group work. In the first class, only 36% of the students earned grades of C or better, while in the classes taught cooperatively, 58% and 65% of the students did so. Those earning A's in the course included 6.4% (first offering) and 11.5% (second offering) of those who worked cooperatively and only 3% of those who worked individually. There was some student resentment about group work in the first cooperative offering and almost none in the second offering, presumably because Tschumi showed the students the comparison between the grades for the lecture class and the first cooperative class.

There are many other proven benefits of cooperative learning that could be explained to the students, such as seeing alternative methods of approaching problems, being able to parcel out large assignments, improving social and communication skills, and gaining self-confidence. However, we find it best not to oversell the approach with long lists of benefits, but rather to let the students discover most of the benefits for themselves. The arguments given above should be sufficient to persuade most students to approach cooperative learning with an open mind. After a while, their own positive experiences provide all the motivation needed.

- *I teach a multicultural class, with many minority students who are at risk academically. Does cooperative learning work in this kind of setting?*

In fact, the greatest cooperative learning success story comes from the minority education literature. Beginning in the mid-1970's, Uri Treisman, a mathematics professor then at the University of California-Berkeley, began to seek reasons for chronically poor performance in calculus by some minority students. He eliminated explanations based on lack of motivation, lack of family emphasis on education, poor academic preparation, and socioeconomic factors, and finally concluded that African-American students, many of whom were failing, studied alone and were reluctant to seek help, while Asian students, who did well, worked in groups. He established a group-based calculus honors program, reserving two-thirds of the places for minority students. The students who participated in this program ended with a higher retention rate after three years than the overall average for all university students, while minority students in a control population were mostly gone after three years. Treisman's model has been used at many institutions with comparable success (Conciatore, 1990).

- *Even though I've done everything the CL literature recommends, some of my students still complain that they don't like working in groups and they would have learned more if they had worked alone.*

  They could be right. Students have a variety of learning styles (see, for example, Felder and Silverman, 1988), and no instructional approach can be optimal for everyone. Moreover, every instructional method - including straight lecturing - displeases some students, so that consistently making all students happy is an unattainable (and in many ways, undesirable) objective for an instructor. The goal should rather be to optimize the learning experience for the greatest possible number of students, and extensive research has demonstrated that when properly implemented, cooperative learning does that.

CONCLUSION

The research and anecdotal evidence confirming the effectiveness of cooperative learning is at this point overwhelming. Regardless of the objective specified, cooperative learning has repeatedly been shown to be more effective than the traditional individual/competitive approach to education.

Obstacles to the widespread implementation of cooperative learning at the college level are not insignificant, however. The approach requires faculty members to move away from the safe, teacher-centered methods that keep them in full control of their classes to methods that deliberately turn some control over to students. They have to deal with the fact that while they are learning to implement CL they will make mistakes and may for a time be less effective than they were using the old methods. They may also have to confront and overcome substantial student opposition and resistance, which can be a most unpleasant experience, especially for teachers who are good lecturers and may have been popular with students for many years.

The message of this report, if there is a single message, is that the benefits of cooperative learning more than compensate for the difficulties that must be overcome to implement it. Instructors who pay attention to CL principles when designing their courses, who are prepared for initially negative student reactions, and who have the patience and the confidence to wait out these reactions, will reap their rewards in more and deeper student learning and more positive student attitudes toward their subjects and toward themselves. It may take an effort to get there, but it is an effort well worth making.

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