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COOPERATIVE LEARNING IN A SEQUENCE OF ENGINEERING COURSES: A SUCCESS STORY

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As part of an ongoing longitudinal study of engineering education, I taught five chemical engineering courses in successive semesters to roughly the same body of students, beginning with the introductory course on chemical process principles (CHE 205) and ending with a senior course in chemical reactor design. The basis for the instructional approach in all five courses was the cooperative learning model articulated by Johnson, Johnson, and Smith, with most deviations from their recommendations being due primarily to my inexperience and/or timidity. The narrative that follows summarizes what I did and how it worked.

CL FORMAT AND RULES

In every course in the sequence, homework assignments were done by fixed teams of three or four students that with few exceptions remained together for an entire semester. The homework consisted of a mixture of standard quantitative problems, problems that called for verbal explanations of physical phenomena, brainstorming exercises, and occasional problem-formulation exercises. *(Make up a nontrivial problem related to the material in Chapter 6 of your text. Make up a problem that involves what we covered this week and what was covered this month in your organic chemistry class.)* The average homework grade counted for about 15% of the final course grade, most of which was determined by grades on individual tests and the final examination. Students who managed to freeload on the homework despite my safeguards against freeloading generally crashed and burned in the course.

I used in-class group exercises in every class period, varying them so that the students never knew what was coming next. Sometimes I would ask the same kind of question I would normally address to the whole class during a lecture. (*What procedure could I use here? Is what I just said correct?*) I might pose a problem and ask the class to outline a solution strategy, estimate the solution or guess what it should look like, get started on the solution procedure and see how far they could get in three minutes, fill in a missing step, or figure out a way to check the answer. I might ask for jargon-free explanations of course concepts. (*Explain in terms a bright high school senior could understand the concept of relative humidity. Explain, in terms of concepts you learned in this course, why you feel comfortable in 65°F air and freezing in 65°F water.*) Sometimes I asked them to generate questions about material just covered, and at other times I had them write and hand in one-minute papers at the end of a class. (*List the major point in the material we covered today. Then list the muddiest point.*)

I also varied the structure of the in-class exercises, sometimes jumping directly into groups, sometimes doing think-pair-shares, and occasionally having pairs work through critical derivations or examples from their text using a TAPPS (thinking-aloud-pair-problem-solving) format. The level of active student involvement in these exercises generally varied between 90 and 100 percent, which is not bad considering that the class size ranged from a high of 125 in the first semester to a low of 90 in the last. (The previous paragraph and this one comprise my response when anyone asks me in a workshop or seminar how they can teach large classes effectively.)

I tried to do a variety of things to help the students learn to function effectively in groups. I regularly required them to summarize in writing what they were doing well as a team, what their problems were, and what if anything they planned to do differently in the future. I advised them and periodically reminded them to set up all assigned problems individually (no detailed mathematical or numerical calculations) and then meet as a group to put the complete solution set together. I warned them about the dangers of one or two students working all the solutions out and then quickly explaining them to teammates who didn't really participate in obtaining them. (This message did not get through to some students until after they flunked the first test.)

I admonished the students not to put a nonparticipating member's name on a solution set, especially if it happened with the same student more than once. I invited teams having serious problems to meet with me to talk things over. Finally, I announced that a team by unanimous consent could fire a chronically non-cooperative member and a team member who constantly had to do most of the work could quit, both options being available only if repeated attempts to correct the problem had failed. Fired students or students who quit had to find teams of three willing to accept them, or else they would get zeros on the remaining homework assignments. Teams almost invariably found ways of working things out before either of those last-resort options was exercised.

The narrative that follows might give professors of technical subjects like engineering, science, and mathematics an idea of what might happen if they try CL on students who have not experienced it before.

CHRONOLOGY

First day of CHE 205: Setting the stage. 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: Introduction to group work. 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: Resistance to group work. 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.

Facilitating effective team functioning. I periodically included group self-assessment questions on homework assignments, and sometimes in class I offered suggestions for effective homework team functioning, trying not to be too preachy about it. 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 groups 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.)

First test results. 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.

Midsemester evaluations. The students were overwhelmingly positive about group work. Almost on a whim, 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 subsequent courses I occasionally assigned individual homework but never again let the students opt out of assigned group work.

Last half of CHE 205: Growth in class cohesiveness, problem-solving skills, and self-reliance. The student lounge began to resemble an ant colony the day before an assignment was due, with 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). Homework grades were almost invariably in the 90's, and many students began to do outstanding work on problems that called for creativity and higher level thinking skills. 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.

"Can you do all this stuff and still cover the syllabus?"

When I give teaching workshops and talk about cooperative learning, an inevitable question has to do whether doing group work cuts down on the amount of material that can be covered in a course. I have several responses, but the principal one is to describe what I did in the experimental sequence. In all courses but the first one I put my notes in coursepaks which the students got on Day 1. The notes had gaps to be filled in and frequent questions like *"Where did this figure come from?"* and *"How do you get from Eq. (4) to Eq. (5)"* and requests like *"Verify this result." and "Convince yourself."* I promised the students that some of these missing pieces would show up on the tests and I kept my promise, so that—especially after the first test—most of the students actually read the notes. As a consequence of using these handouts, I saved untold hours of class time that would have been wasted on writing detailed derivations and prose on the board and instead used those hours for active learning exercises. By their own estimation and mine, the students learned far more from the exercises than they would have from the stenography, and I ended up covering *more* material in each course than I had gotten through when all I did was lecture.

EVALUATION

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.

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. 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. Women generally gave CL higher ratings than men, but they were also more likely to complain that their ideas were devalued or discounted within their groups and they tended to take less active roles in group discussions. Gender differences in CL groups are discussed in greater detail in the final bibliography reference.

Of the students who took the introductory course as sophomores in the Fall of 1990, roughly 80% had either graduated or were still enrolled in chemical engineering after their fourth year of college, a retention rate significantly higher than normal in this major. (We are currently generating precise comparisons.) Sixty percent of the seniors 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.

My own observations corroborated the students' opinion that cooperative learning had improved their educational experience. For one thing, they came to class regularly: attendance on any given day was normally 90% or better, which is far from what we usually see in lecture classes of the size I was teaching. They tended to do better on tests than any other class I ever taught, even though the tests called on them to exercise a greater variety of thinking and problem-solving skills than any I had previously given. I also observed a greater sense of community in this cohort of students than I had seen in any other chemical engineering class in my 25 years in the profession. Almost from the outset of the study, they worked 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.*"

One episode in particular led me to believe that group work was having the desired effect on the students' intellectual development. 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!

Moving to CL is not an easy step for professors of technical subjects (or any other subjects, for that matter). 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 more familiar teacher-centered 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.

EPILOGUE: WHAT DO I DO DIFFERENTLY NOW?

When I began the study, I was fairly low on the CL learning curve. I still use it extensively in every class I teach, but I do some things differently than I did in the longitudinal study, in part because of what the study taught me. I now form groups myself rather than letting the students self-select. On the first day of class I circulate a questionnaire asking for grades in selected prerequisite courses, sex, race, interests, and times available for group work outside class, and I form groups that are heterogeneous in ability (as measured by those grades) and share common interests and possible meeting times. I also try to avoid groups in which women are outnumbered by men and ethnic minorities are outnumbered by white students; my study data and the literature suggest the gender policy and the ethnic policy is my extrapolation of those results. I discuss the rationale for CL up front more than I used to, using a variety of sales pitches that I have found effective for engineering students. Finally, I have increased the frequency of group self-monitoring exercises, finding that the more frequently problems are placed on the table, the less likely they will be to explode into crises.