Promoting collaborative groups in large enrollment courses

Robert J. Beichner, Jeffery M. Saul, Rhett J. Allain,
Duane L. Deardorff, David S. Abbott
North Carolina State University

Abstract

SCALE-UP is an extension of the highly successful IMPEC project (Integrated Math, Physics, Engineering, and Chemistry), one of NC State's curricular reform efforts undertaken as part of the SUCCEED coalition. Basically, we are utilizing the highly interactive, collaboratively-based instruction that worked so well in smaller class settings and finding ways to economically accommodate classes of 100 students. Relative to students taught in traditional classes, SCALE-UP students are better problem solvers, achieve nearly four times the gain on certain conceptual tests, have better attitudes toward science, and report greater satisfaction with their instruction. Retention rates for females are twice those in regular classes. Technology is used to provide a phenomenological focus for students, allowing data collection, analysis, mathematical modeling, and advanced simulations. As student attention is drawn into analyzing different physical situations, teachers circulate around the room and engage students in Socratic dialogs. Lecturing is minimal, primarily for motivation and to provide an overview of topics. Use of WebAssign, a web-based problem delivery and grading system, ensures that students have reviewed the textbook before attending class. This technology also permits students to conduct peer evaluations of each other's work. This poster presentation describes some of the different protocols we utilize to facilitate group functioning; including group member selection, contracts, team self-evaluations, scoring to promote participation by the better students in group activities, requirements for team presentations, etc. Examples of evaluation forms, activities to introduce the benefits of teamwork, and teacher guidelines will also be on display.

I. Introduction

A description of the SCALE-UP project can be found in the paper "SCALE-UP (Student-Centered Activities for Large Enrollment University Physics)" in session 2380. The basic idea is that we have merged lecture and lab classtime into a course that stresses activities by the students. We have tested a variety of classroom layouts and experimented with different course management techniques. We have been very pleased with the performance of a redesigned classroom in promoting active and collaborative learning.

II. Description of the posters

The **first poster** shows the room before renovation. It was a crowded, traditional classroom with 55 desks. As you can see, there has been a dramatic change in the appearance of the room, which now holds 54 chairs. Each 6' round table supports interactions between and within three teams of three students each, with each team sharing a laptop computer. The flexible seating allows students to arrange themselves for the most convenient working space. This is important because of the wide variety of activities they work on during class. One of the photos shows students measuring the coefficient of friction between their books and the table surface. Note how they have placed themselves in different locations and have (rather precariously!) moved the laptop out of their way. **Poster 2** shows the design of the new classroom for 99 students that will be in use in the Fall of 2000.

The redesigned classroom (supporting 54 students) has been very successful in establishing the desired learning environment. Students readily work in their own teams of three as well as in table-sized groups of nine. Each table of students seems to become its own little society and develops a unique personality. Students particularly enjoy having each table work on a problem and then sharing their efforts with the rest of the class using the whiteboards that surround the room. Of course, each individual student is responsible for all the problems, ensuring good questioning when something is not clear in a table's presentation to the rest of the class. Examples of the complicated "Real World Problems" that the student teams work on is shown on the **third poster**. Tables are chosen (by rolling dice) to present their solutions to the problems. Their classmates evaluate the quality of the presentations using the criteria on **poster 4**. An important part of their solutions is the use of the GOAL problem solving protocol outlined on **poster 5**.

We have modified a variety of research-based instructional materials for the larger class sizes of this project. "Ponderables" are short paper and pencil activities that can be worked individually or in groups. "Tangibles" are brief hands-on tasks that are normally group-based. Examples of both are on **poster 6**.

In addition to the short tangible activities, we also have more extensive, group-based laboratory work that requires a formal report. Following suggestions from the collaborative learning literature, as part of their lab each individual examines the teamsmanship of themselves and their group mates. (See **poster 7**.) The quality of their evaluation is worth 10% of the lab grade. We also have created practical lab exams where each student must demonstrate every skill required for a lab. This has worked well to insure that everyone gets an opportunity to use all the equipment and thoroughly understand all parts of the lab. Thus individual accountability and group responsibility are built into each lab activity.

We have taken a number of steps to promote successful groups. These are outlined on **poster 8**. The groups are carefully chosen so that each group is heterogeneous in academic background, but on average, is the same as all the other groups. Early in the semester students receive training in group functioning and create their own contracts of responsibility, examples of which are shown on **posters 9 and 10**. We have a well-defined protocol so that teams can "fire" lazy group members. This is a serious situation since about ¼ of the total grade comes from group submissions. Many of the assigned tasks are simply too difficult to tackle individually, so students avoid being fired. In the six years of this project and its precursor studies, only one group has had to fire a member. Students at the other end of the spectrum–those who would feel "held back" by the rest of their classmates–are encouraged to participate by a sharing of bonus points on exams. If the team average on any given test is 80% or better, each team member has 5 points added to their score. Thus it is in the best interest of the top students to teach the others in their group. Of course, grades are not curved, but based on the achievement of well-specified objectives.

Results from focus groups and individual interviews have been quite encouraging. Students seem to genuinely enjoy working together, as illustrated in these quotes from transcribed audio tapes:

> "I can deal with the lecture class, it is just that I enjoy more...getting more into the interactive projects. It is more hands on. If you don't understand something you just ask the guy next to you, nobody yells at you for talking."
>
> " …you have your professor right in the middle and you have a couple of guys spread out and you can flag them down –'Hey, can you answer this question for me?' In the lecture, you are sitting 100 rows back, 25 rows back, you really don't have anyone but the two people next to you and they don't know. You really don't have anyone with some knowledge to help you out."

It is interesting to contrast the opinion the speakers have for their classmates in the two different learning environments.

A much more detailed discussion of the evaluation of the project is available in paper "Evaluating introductory physics classes in light of the ABET criteria: An example from the SCALE-UP Project" from session 1280.

We welcome inquiries from others interested in making large-enrollment classes more interactive. We have begun to develop instructional materials which we will freely share. A sample of the teacher guide dealing with setting up cooperative groups is found on **poster 11**. Additional information can be found at www.ncsu.edu/PER or by contacting the author at Beichner@ncsu.edu.

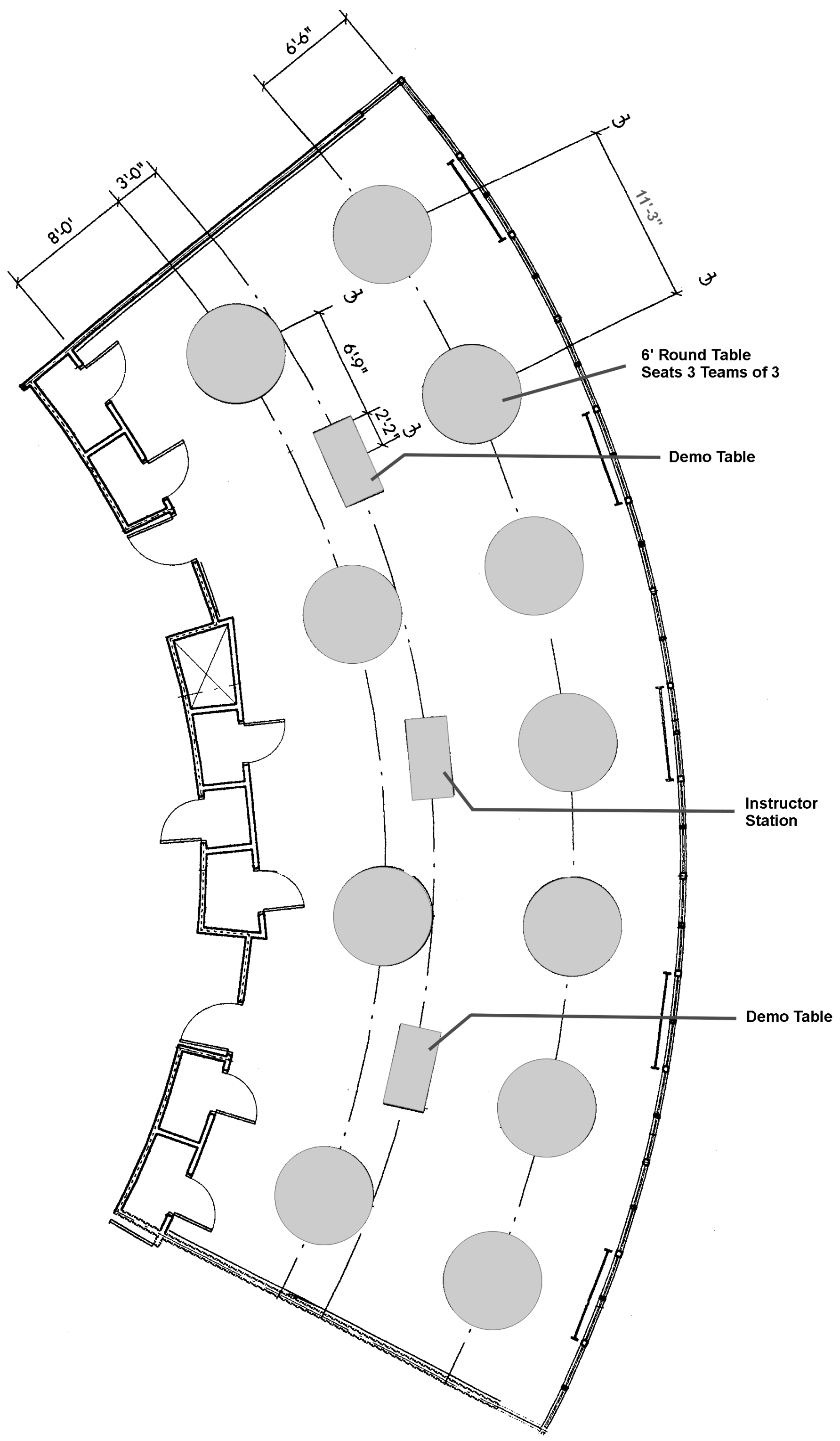
Space Redesign to Support Cooperative Groups

Before (seating 55)

After (seating 54)

New Classroom opening Fall 2000

Supporting active, cooperative learning for 99 students



Examples of Real World Problems

(Assigned on Wednesdays, solutions presented by students on Fridays)

Some involve student interests:

- You are at a Durham Bulls **baseball game**, waiting for another home run by the Bulls so you can see the giant “bull board” flash its red eyes, blow smoke through its nose, and swing its tail. You have been watching the digital display that shows the speed of each pitch as measured by the radar gun behind the catcher. Now you wonder how fast the ball travels off the bat when one of the players hits a home run over the 8-foot outfield wall. You notice the distance markers at the end of the left, center, and right-field lines: respectively 305, 326, and 400. With this information, you realize that you can use the physics you have learned to answer your own question.

Some relate to technical jobs:

- You have a job with a semiconductor processing lab that uses MBE (molecular beam epitaxy) to make transistors and other multi-layer electronic devices. A quartz crystal oscillator is used to **measure the thickness of a thin film** being deposited on a sample in the vacuum chamber. The crystal monitor is vibrated by a frequency generator and operates essentially like a mass on a spring so that the 6 MHz characteristic resonant frequency of the crystal is reduced as more material is deposited on its surface, which is exposed to the same conditions as the sample. The crystal has an exposed diameter of about 1 cm and a mass of about 0.1 g. The digital display for the instrument shows 4 digits. What is the resolution (smallest change in thickness) of this instrument? (Hint: How does a change in mass correspond to a change in the frequency of oscillation?)

Some are just fun:

- You are a technical advisor to the Dave Letterman Show. Your task is to design a **circus stunt** in which **Super Dave Osbourne**, who weighs 170 pounds, is shot out of a cannon that is elevated 40 degrees from the horizontal. The "cannon" is actually a 3-foot diameter tube that uses a stiff spring and a puff of smoke rather than an explosive to launch Super Dave. According to the manufacturer, the spring constant of the cannon is 1800 N/m. The spring is compressed by a motor until its free end is level with the bottom of the cannon tube, which is 5 feet above the ground. A small seat is attached to the free end of the spring for Super Dave to sit on. When the spring is released, it extends 9 feet up the tube. Neither the seat nor the chair touch the sides of the 12-foot long tube. After a drum roll, the spring is released and Super Dave will fly through the air amidst sound effects and smoke. There is a giant airbag 3-feet thick and 10 feet in diameter for Super Dave to land on. Where should this airbag be placed for Super Dave to have a safe landing?

- **Super Dave** has just returned from the hospital where he spent a week convalescing from injuries incurred when he was "shot" out of a cannon to land on an airbag which was too thin and improperly placed for a safe landing. Undaunted, he decides to celebrate his return with a new stunt. He intends to jump off a 100-foot tall tower with a **bungee cord** tied to one ankle, and the other end tied to the top of the tower. This elastic cord is very light but very strong and stretches with a linear spring force so that it can stop him without pulling his leg off. For dramatic effect, Dave wants to be in free fall as long as possible, but you know that his maximum acceleration should not exceed 5g for his own safety. You have been assigned to purchase the cord for the stunt, so you must determine how long the bungee cord should be and the elastic force constant that characterizes the cord. Before the calculation, you carefully measure Dave's height to be 6.0 ft and his weight to be 170 lbs.

(Many of our Real World Problems are modified from materials created by the Physics Education Group at the University of Minnesota.)

Rating Criteria

(used by students for evaluating their peers' Real World Problem presentations)

Determine a total score (up to 10 pts) and brief justification for each of the three groups giving presentations.

1. Did the table preparing for the presentation make an effort to not disturb those around them who were taking the quiz? (2 pts)

2. Based on the quality of their presentation (clear speech, concise and understandable discussion, use of GOAL, etc.), select from the following:

Working alone but using your notes from their presentation,

You could solve the problem completely (8 pts)

You could produce most of the problem solution. (6 pts)

You could only outline the problem solution. (4 pts)

You could only state the general principles involved in the problem solution. (2 pts)

You could not solve the problem at all. (0 pts)

Problem Solving Protocol used by teams

Besides what you might expect to learn about physics concepts, a very valuable skill you should hope to take away from your physics course is the ability to solve complicated problems. The way physicists approach complex situations and break them down into manageable pieces is extremely useful. We have developed a memory aid to help you easily recall the steps required for successful problem solving. When working on problems, the secret is to keep your GOAL in mind!

GOAL Problem-Solving Steps

Gather information

The first thing to do when approaching a problem is to understand the situation. Carefully read the problem statement, looking for key phrases like "at rest" or "freely falls." What information is given? Exactly what is the question asking? Don't forget to gather information from your own experiences and common sense. What should a reasonable answer look like? You wouldn't expect to calculate the speed of an automobile to be 5×10^6 m/s. Do you know what units to expect? Are there any limiting cases you can consider? What happens when an angle approaches 0° or 90° or when a mass becomes huge or goes to zero? Also make sure you carefully study any drawings that accompany the problem.

Organize your approach

Once you have a really good idea of what the problem is about, you need to think about what to do next. Have you seen this type of question before? Being able to classify a problem can make it much easier to lay out a plan to solve it. You should almost always make a quick drawing of the situation. Label important events with circled letters. Indicate any known values, perhaps in a table or directly on your sketch.

Analyze the problem

Because you have already categorized the problem, it should not be too difficult to select relevant equations that apply to this type of situation. Use algebra (and calculus, if necessary) to solve for the unknown variable in terms of what is given. Substitute in the appropriate numbers, calculate the result, and round it to the proper number of significant figures.

Learn from your efforts

This is the most important part. Examine your numerical answer. Does it meet your expectations from the first step? What about the algebraic form of the result–before you plugged in numbers? Does it make sense? (Try looking at the variables in it to see whether the answer would change in a physically meaningful way if they were drastically increased or decreased or even became zero.) Think about how this problem compares with others you have done. How was it similar? In what critical ways did it differ? Why was the problem assigned? You should have learned something by doing it. Can you figure out what?

When solving complex problems, you may need to identify a series of subproblems and apply the GOAL process to each. For very simple problems, you probably don't need GOAL at all. But when you are looking at a problem and you don't know what to do next, remember what the letters in GOAL stand for and use that as a guide.

From Serway and Beichner, Physics for Scientists and Engineers, 5th ed., Saunders College Publishing, 2000.

Examples of Ponderables: “Minds-on” Activities

- How many two-step paces is it from LA to NYC?
- How far does a bowling ball get before it stops skidding and is only rolling?
- Which glasses in the figure below correct for nearsightedness?

(a) (b)

Examples of Tangibles: “Hands-on” Activities

- What is the thickness of a single page from your text?
- What is the frequency of the sound produced by blowing across the top of a soda pop bottle?
- Find the coefficient of kinetic friction between your book and the table.
- Find the number of excess charges on a piece of tape pulled off the table.

Teamsmanship Ratings

Name ______________________________ Group ________

(Please fold this paper in half before handing it in.)
Write the names of all your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the homework assignments. The possible ratings are as follows:

Excellent	Consistently went above and beyond--tutored teammates, carried more than his/her fair share of the load
Very Good	Consistently did what he/she was supposed to do, very well prepared and cooperative
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative
Marginal	Sometimes failed to show up or complete assignments, rarely prepared
Deficient	Often failed to show up or complete assignments, rarely prepared
Unsatisfactory	Consistently failed to show up or complete assignments, unprepared
Superficial	Practically no participation
No show	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability. You will be graded on the quality of the evaluation. In other words, you need to thoroughly justify your decisions.

Name of team member	Role(s)	Rating	Justification

Your signature ________________________________ adapted from R. Felder

Cooperative Grouping

- Individual accountability. Each member is responsible for doing their own fair share of the work and for mastering all the material.
- Positive interdependence. Team members have to rely upon one another.
- Face-to-face interaction. Some or all of the group effort must be spent with members working together.
- Appropriate use of interpersonal skills. Members must receive instruction and then practice leadership, decision-making, communication, and conflict management.
- Regular self-assessment of group functioning. Groups need to evaluate how well their team is functioning, where they could improve, and what they should do differently in the future.

Sample Student-Generated Group Contracts

Group Contract

We agree to:

1) attend regularly scheduled meetings.
2) be on time for meetings.
3) give notice in case of absence.
4) respond promptly to messages.
5) look over group work before meetings.
6) attend class.
7) get notes to absent group members.
8) rotate positions evenly.
9) be responsible for individual assignment.
10) schedule weekly meetings

We agree to:
1. come to class
2. Make sure that when we miss class that we contact the others in our group.
3. That we will work assignments collaboratively
4. Switch roles per assignment
5. show up to meetings
6. complete asignments before group meetings
7. assist others having trouble with the assignments.

This group contract is binding upon all who sign it and is subject to change with prior approval of all members of the group.

Group Contract

Instructions: Please initial all clauses of this contract you are committed to following. An initial implies that you are committing yourself to abide by the clause next to it.

A. I agree to come to class on a regular basis.

B. In the result that I am unable to attend class, I will make it my personal responsibility to get any and all notes from my group.

C. Under any and all circumstances, I will get what work I am allotted to do, done and turned in on time.

D. If I am sick and unable to make it to class on the date a group assignment is due, I will call my group members to make other arrangements to get my work turned in on time.

E. The time and place of group meetings shall be agreed upon unanimously within our group.

F. I will be in attendance and prompt for each and every group meeting.

G. Should an emergency arise that prevents me from attending a group meeting, I will notify my fellow group members immediately.

H. I will do my share of the group work, there will never be an occasion where one group member does all of the work nor will there be a time when a group member does none of the work.

I. Each member will agree on the answer for each group problem before it is turned in. In circumstances where agreement is not automatic, each member shall explain how they arrived at their particular solution until a correct solution is clear. If no agreement can be reached, a vote will be taken on which result to submit.

J. I will do everything in my capabilities to help my fellow group members understand each and every concept and problem.

K. If I do not understand a concept or a solution, I will not hesitate to ask my fellow group members for help.

L. I will communicate with my fellow group members about any concerns I have with our group work.

M. I will be an active member of this group in all aspects. I will not take answers as fact, but instead confirm final results by working the problem myself and attempting to get the same solution.

I certify that I have thoroughly read this contract and that I will abide by it. I am signing this contract at my own free will, and have initialed each of the above statements because I agree with it, and am willing to adhere to each clause. I understand that breach of contract will result in verbal reprimand on the first two instances, followed by immediate dismissal on the third instance. This contract is subject to be amended pending a unanimous vote within the group. By signing below I certify that I am bound, by contract, to obey each and every clause I have initialed and understand that breach of contract will result in a maximum of two verbal reprimands and on third offense, dismissal from the group.

name ______________ date 8/27/99

name ______________ date 8/27/99

name ______________ date 8/27/99

Cooperative Learning

"The best answer to the question, 'What is the most effective method of teaching?' is that it depends on the goal, the student, the content, and the teacher. But the next best answer is, 'Students teaching other students." McKeachie, W. (1994) *Teaching Tips*, 9th ed. Lexington, MA, Heath & Co.

As you might guess from the name, cooperative learning (CL) involves students working in groups on structured tasks. However, CL is *not* students sitting around a table studying together or assigning group projects where one student ends up doing most of the work. According to countless studies, there are five absolutely critical aspects of successful cooperative learning. Omit one or more of the items on the following list and group work will almost certainly fail in your classroom. The five defining aspects of CL are:

1. *Positive interdependence*. Team members have to rely upon one another.
2. *Individual accountability*. Each member is responsible for doing their own fair share of the work and for mastering all the material.
3. *Face-to-face interaction*. Some or all of the group effort must be spent with members working together.
4. *Appropriate use of interpersonal skills*. Members must receive instruction and then practice leadership, decision-making, communication, and conflict management.
5. *Regular self-assessment of group functioning*. Groups need to evaluate how well their team is functioning, where they could improve, and what they should do differently in the future.

These criteria can be found throughout the literature. If you are interested in more details visit Richard Felder's website www2.ncsu.edu/effective_teaching/ or read D.W. Johnson, R.T. Johnson, and K.A. Smith, *Active Learning: Cooperation in the College Classroom*, 2nd Ed. Edina, MN, Interaction Book Co., 1998. Many of the ideas listed here come from these two sources.

The benefits of CL include improved student-faculty and student-student interaction, information retention, academic achievement, higher-level thinking skills, attitudes, motivation to learn, teamwork and interpersonal skills, communication skills, self-esteem, attendance, race/gender relations and reduced levels of anxiety. Although this seems like a huge list, there are numerous studies where these results have been carefully documented. Of course, for the teacher there are fewer and better papers to grade. There is quite a bit of educational psychology behind why CL techniques work so well (if all 5 aspects are present). These include the fact that the learning is done in an active manner, groups keep going when individuals might give up, students see alternative problem-solving approaches, more and higher quality questions are produced, there is less fear in class, and as noted in the quotation above, people learn best when they teach.

There are basically two different strategies for implementing cooperative learning: informal and formal. The informal methods can be put into practice "on the fly" during class.

Informal CL Structures

For all of these techniques, be sure you clearly explain the task, randomly call on students to report, circulate around the room and listen, and don't get into a pattern of always alternating short lectures with CL. Variety is the spice of life!

- In-class teams: Divide students into groups of 2 to 4 students and choose a recorder ("Who has the longest last name in your group?", "Who got up earliest this morning ?" or similar questions are icebreakers and automatically select a variety of recorders.) Give the teams a couple of minutes to recall prior material, answer a question, start a problem solution, work out the next step in a derivation, think of an example or application, figure out why a given result may be wrong, identify underlying assumptions in a solution, brainstorm possible answers to a question, generate an exam problem, summarize material, etc. Collect some or all the answers.

- Think-Pair-Share: Ask a question that requires careful consideration (perhaps from Eric Mazur's *Peer Instruction: A User's Manual*, 1997, Upper Saddle River, NJ, Prentice-Hall). Give students a minute or two to think about the problem individually. Have them pair up to discuss and produce an answer agreeable to both, and then select teams to share their answers with the class. Be sure to elicit comments on answers that changed and why the pair decided a particular answer was right or wrong. Students don't need to say which member of the pair had the original, incorrect answer so you will be more likely to hear reports of the kinds of misconceptions that are commonly seen. If students don't mention a particular misunderstanding that you know is widespread, bring it up for discussion. You can be sure that someone in the room was thinking along those lines and could benefit from a re-examination of their understanding.

- Cooperative Note-Taking Pairs: At the beginning of class, pair up the students. Every once in a while during class, pause and have one partner summarize their notes to the other. The other person can add information, ask for clarification, or make corrections. The goal is for everyone to improve his or her note taking ability.

- Guided Reciprocal Peer Questioning: Have students work in teams of three or four give them a collection of "generic question" stems like these:

How does … relate to what I've learned before?
What conclusions can I draw about …?
What is the difference between … and …?
What are the strengths and weaknesses of …?
What is the main idea of …?
What is a new example of…?
What is the best … and why?
What is … important?

What if …?
Explain why …
Explain how …
How are … and … similar?
What is the meaning of …?
How would I use … to …?
How does … affect …?

Have each student prepare several thought-provoking questions. Form groups of two or three and have members answer the individually-created questions. Bring the whole class together to discuss particularly interesting or problematic questions. For additional ideas, see King, A. (1993). "From sage on the stage to guide on the side," *College Teaching, 41* (1), 30-35.

➢TAPPS (Thinking Aloud Pair Problem-Solving): Have students do this with key problems or an important derivation. This activity takes a lot of time, but it is very powerful. It works well in conjunction with the different steps of the GOAL problem-solving protocol. Start by forming pairs, with one student being the problem-solver and the other the listener. Present the problem to the teams and assign a specific portion to be the focus of effort. The solver talks through the first part of the solution while the listener questions, prompts the solver to keep talking (that's the thinking aloud part), and gives a few clues, if needed. After a few minutes, collect partial solutions from several listeners (not solvers) and reach a classwide consensus. Reverse the roles and have the teams continue. More detailed instructions can be found in Lockhead, J. & Whimbey, A. (1987). "Teaching analytical reasoning through thinking aloud pair problem solving. In J. E. Stice (Ed.), *Developing critical thinking and problem-solving abilities: New directions for teaching and learning, No. 30,* San Francisco: Jossey-Bass.

Formal CL Structures

One thing you don't want to do when getting ready to implement formal CL approaches is to let students select their own groups. In order for everyone to be treated fairly, the groups must be heterogeneous in ability. This can be done by reviewing GPA or other background information provided by your university. Another method that is useful is to give students a diagnostic test at the beginning of the semester. Not only will this help you form groups, but it gives you a "before snapshot" so that you (and your students) can see how far they've come by the end of the semester. Once you have a ranked list of students in a class, simply divide them into top, middle, and bottom thirds. (Don't tell the students how the groups were selected or they'll spend the rest of the semester worrying about whether they are the "slow kid on the team.") Select a student from each ability level to form groups of three. There are additional constraints on these selections: (1) Don't pick people you know are already friends to be teammates. The other person in the group may not fit in well. (2) If you can collect schedule information, try to make sure there are common times the teams can get together outside of class. (3) Don't let underrepresented populations (usually women or minorities) be outnumbered in a group. Studies have shown that this precaution reduces the tendency for contributions from these students to be minimized.

You will need to explain to your students why you are having them work in groups. This may be a new idea to them. If they are engineering students, simply remind them that they must work with other people before they can get their professional license. This is certainly the way the workplace operates now. There are numerous employee surveys illustrating that team skills are a top hiring criterion. If nothing else, explain how it will help them learn!

Once groups are formed, keep them intact for at least a month while students work out the any difficulties that arise. Again, remind them that they generally won't get to pick who they work with on the job. With guidance from you, have each team write a contract listing goals and expectations. Have each member sign their contract, make copies for the team, and submit the original for your files. It helps to have samples available. Brainstorming characteristics of a successful group is also a useful exercise. You will almost certainly need to provide teamwork instruction. Visit the excellent Collaborative Learning Website at www.wcer.wisc.edu/nise/cl1 or download the *Team Training Workbook* from www.eas.asu.edu/~asufc/teaminginfo/teams.html.

Make a concerted effort to support the five criteria mentioned earlier. To help promote positive interdependence, assign different roles (manager, recorder, skeptic) to group members. Give critical information only to the manager. Rotate roles periodically or for each assignment. Provide one set of resources and require a single product. Don't forget to require individual accountability—use primarily individual testing. Have someone in the group routinely checking everyone's understanding. Call on individuals to present and explain results (while groups are working and after work is complete). Make groups responsible for seeing that non-contributors don't get credit. Get each member to rate everyone's contribution, including their own. Make sure they explain their ratings. Provide last resort options of firing a group member or quitting. Although this seems silly, if a substantial portion of the grade comes from group work, there is considerable motivation to be part of a group if that is the only way those assignments can be submitted.

It is especially important that you do not curve course grades. It should be possible for everyone in the class to earn an "A" (or an "F"). If students know that their grade depends on them doing better than others in the class, there isn't much motivation for cooperation. Establish a set of objectives for each topic and provide students with a syllabus that clearly delineates cutoff points. Students are much more motivated to perform if they know exactly what is required of them and the consequences of not performing.

Several formal structures to facilitate collaborative learning are listed below. More can be found in the references noted throughout this section and on the web. Forms to support team self-assessment along with instructor checklists for each of the techniques below are available on the SCALE-UP website.

- Team homework: Assignments are completed and handed in by teams. (Only active participants' names are included on materials submitted for grading.) One grade is given for the entire team, although it is possible to adjust the academic score by incorporating members' "teamsmanship" scores. For problems sets, it is a good idea to have each individual outline a solution to each problem before getting together to complete the solutions. You can enforce this by occasionally collecting everyone's outlines. Beware of the tendency of groups to "divide and conquer" an assignment by having individuals finish entire problems on their own and simply collecting the results. They don't get the benefit of group thinking and it's hard to make sure that everyone understands all aspects of the assignment.

- Team projects: You can illustrate the value of groups by giving assignments that would be too difficult or too much work for an individual to complete in a reasonable amount of time. These can include designing something, creating web pages discussing the physics of familiar devices or situations, giving presentations to the class, etc. See the Jigsaw technique for a way to facilitate this type of effort. Each team gets a single grade that may be adjusted for individual contributions.
- Jigsaw: Individual group members have access to resources that the others don't have. These could be something as simple as a handout describing a specific portion of their task or even specialized instruction that only one member of a team receives. This fosters interdependence within the group and encourages learning as each individual shares what they know with the others. To set up the "expert areas" within each group, give each team member a number: 1, 2, or 3. Gather all the #1 people together and give them their particular set of information. Do the same with the #2 and #3 people. Then they can get together (either in class or out of class) to complete the task. This approach also works nicely when students study for a test. Each member becomes an expert on a particular topic and makes sure his or her teammates thoroughly understand it.
- Group bonus: If the average exam score for a group is above 80 or some other value you decide upon in advance, each member of the group gets an additional 5 points added to their score. (Do *not* require that each individual score be above the cutoff. This puts tremendous pressure on the lower performing student.) This technique has been very successful in promoting learning. It is a wonderful way to motivate the more advanced student to participate in group work rather than feel "pulled down" by the others in the team. Of course, if you recall from when you first taught a course, it is in teaching others that we really gain understanding. So the brighter student benefits at least as much as the others in the group.
- Individual Test followed by Group Test: Hand out exams as you normally do. After a specified time, collect the tests but then allow teams to work together on the same problems. Incorporate performance on the group test into the individual scores, perhaps by giving a bonus if the group test is above 90% or add some fraction of the points earned on the group test.

ROBERT J. BEICHNER
Robert Beichner is Associate Professor of Physics at the North Carolina State University. He received B.S. degrees in Physics and Mathematics from Pennsylvania State University and a M.S. in Physics from University of Illinois. His Ph.D. from SUNY at Buffalo is in Science Education. His research interests are in student learning of physics. He recently completed work on the 5 th edition of Serway and Beichner, *Physics for Scientists and Engineer*s, a leading introductory textbook.

JEFFERY M. SAUL
Jeff Saul is a post-doctoral research assistant in the physics education research and development group at North Carolina Sate University. He received a B.S. degree in Applied Physics from University of California at Irvine and received the first Ph.D. in Physics in physics education research from University of Maryland under Edward F. Redish. His current research interests are in student learning of physics and development of active-learning introductory physics curricula. In addition, he is an author of the instructor's manual to *Physics for Scientists and Engineers* by Ray Serway and Robert Beichner.

DUANE L. DEARDORFF
Duane Deardorff is currently a graduate student at North Carolina State University pursuing a Ph.D. in physics. He received a B.A. in physics with distinction from Manchester College. His current research interests are in student learning of physics in introductory physics classes, with an emphasis on studying student understanding of measurement and uncertainty. In addition, he is a contributing author for the student study guide and the instructor's manual to *Physics for Scientists and Engineers* by Ray Serway and

DAVID S. ABBOTT
David Abbott is currently a graduate student at North Carolina State University pursuing a Ph.D. in physics. He received a B.S. degree in Physics from University of Delaware. After receiving his M.S. degree from University of Virginia, David taught physics as adjunct faculty at Delaware Technical Community College and other community colleges for five years. He is pursuing his Ph.D. dissertation research under a National Science Foundation grant to study use of technology for improving student learning in introductory physics classes.

RHETT J. ALLAIN
Rhett Allain is currently a graduate student at North Carolina State University pursuing a Ph.D. in Physics. After receiving his M.S. degree in Physics from the University of Alabama, Rhett was an assistant professor at Judson College in Marion, Alabama. His current research interests are in student learning of physics in introductory physics courses, particularly student understanding of electric potential difference and developing student activities using computer-assisted peer evaluation. In addition, he is a contributing author for the instructor's manual to Physics for Scientists and Engineers by Ray Serway and Robert Beichner.