# Cooperative Problem Solving


# I. How Do I Form Cooperative Groups?

The learning advantage of CPS lies in the students' *co-construction* of a problem solution. There are several aspects of group structuring that affect learning, such as group size, group composition, how long groups stay together, and the roles of individual students in the groups. Our recommended structures and their rationale are described in this section. The Figures contain a brief description of the research that supports each structure (taken from our published papers[1,2]), so they can be skipped or read, as you like.

## Group Size and Assignment

We found that the optimal group size is three. Of course, if your class is not divisible by three, then you will have a few pairs or a four-member group. We found that four-member groups generally work better than pairs in discussion sections. For the laboratory, break the group of four into two pairs.

We recommend assigning students to groups, rather than letting students form their own groups. Below are the advantages of group assignment.

Optimal Learning. The **most important** reason to assign students to groups is because 25 years of past research in cooperative group learning (including our own) indicates that students learn more when they work in ***mixed-achievement groups*** (i.e., based on past test performance) than when they work in homogeneous-performance groups. We do not, however, want students to wonder whom the high, medium and lower-performance students are in their groups, and so we do not tell them directly that this is how we assign group membership.

Psychological Advantage. There is a psychological reason for assigning groups. This reason is so important we called it the 2nd Law of Instruction:


Don't change course in midstream. Instead, structure early then fade.

It is much easier to set and enforce rules in the beginning of a class and loosen the enforcement later than it is to not have any rules at the beginning, and discover later that you have to establish a new rule. If you assign groups at the beginning, you will have fewer disgruntled students.

**Figure 1. Why are three-member groups better than pairs or four-member groups?**

For the co-construction of a physics problem solution by students in introductory courses, we found the "optimal" group size to be **three** members. A three-member group is large enough for the generation of diverse ideas and approaches, but small enough to be manageable so that all students can contribute to the problem solution.

An examination of written group problem solutions indicated that three- and four-member groups generate a more logical and organized solution with fewer conceptual mistakes than pairs. About 60 - 80% of pairs make conceptual errors in their solution (e.g., an incorrect force or energy), whereas only about 10 - 30% of three-or four member groups make these same errors. Observations of group interactions suggested several possible causes for the lower performance of pairs. Groups of two did not seem to have the "critical mass" of conceptual and procedural knowledge for successful completion of context-rich problems. They tended to go off track or get stuck with a single approach to a problem, which was often incorrect.

With larger groups, the contributions of the additional student(s) allowed the group to jump to another track when it seemed to be following an unfruitful path. In some groups of two, one student dominated the problem solving process, so the pair did not function as a cooperative group. A pair usually had no mechanism for deciding between two strongly held viewpoints except the constant domination of one member, who was not always the most knowledgeable student. This behavior was especially prevalent in male-female pairs. In larger groups, one student often functioned as a mediator between students with opposing viewpoints. The issue was resolved based on physics rather than the personality trait of a particular student.

In groups of four students, however, one person was invariably left out of the problem solving process. Sometimes this was the more timid student who was reticent to ask for clarification. At other times, the person left out was the most knowledgeable student who appeared to tire of continually trying to convince the three other group members to try an approach, and resorted to solving the problem alone. To verify these observations, we counted the number of contributions each group member made to a constant-acceleration kinematics problem from the videotapes of a three-member and four-member group. Each member of the group of three made 38%, 36%, and 26% of the contributions to the solution. For the group of four, each member made 37%, 32%, 23%, and 8% of the contributions to the solution. The only contribution of the least involved student (8%) was to check the numerical calculations. Our results are consistent with the research on precollege students.[3]

`Practical Advantage.` There are practical reasons for assigning students to groups. For example, most of our students do not know each other at the beginning of class. They would feel very uncomfortable being told simply to "form your own groups." Even if students know each other well, they typically have established behavior patterns that are not based on learning physics and are not conducive to it. Assigning groups allows the natural breakup of existing social interaction patterns.

## Changing Groups

There are both optimal-learning and practical reasons for changing groups.

Avoid Homogeneous Groups. One reason to change groups is that you are likely to have many homogeneous-achievement groups, which is not optimal for student learning. Normally you do not know the problem-solving performance of your students at the beginning of class. With a small number of students, there can be large random fluctuations in the achievement-mix of your groups.

Avoid of Role Patterns. In groups, the necessity to verbalize the procedures, doubts, justifications and explanations helps clarify the thinking of all group members. In addition, students can rehearse and observe others perform these roles, so they become better individual problem solvers. If students stay in the same group too long, they tend to fall into role patterns. The result is that they do not rehearse the different roles they need to perform on individual problems, and consequently do not achieve optimal learning gains.

Difficult Students. A third, practical reason for changing groups is that your first groups may have some very dysfunctional groups (because of personality conflicts). Students find it miserable to contemplate working a whole term with someone who isn't compatible, and may disengage. However, most will accept the challenge of working together if they know that it is for a limited time. After you get to know the students better, you can place the "difficult" students in a better group. Strategies for dealing with difficult group members are discussed in Section III.

Individual Responsibility. Finally, one of the most important reasons to change groups is to reinforce the importance of the individual in cooperative problem solving. The most difficult point in the course for group management is the first time you change groups. By that time, most groups have been reasonably successful, and students are convinced they are in a "magic" group. Changing groups elicits many complaints, but is necessary for students to learn that success depends on individual effort and not on a particular group.

So how often should groups be changed? Students need to work in the same group long enough to experience some success. The frequency of changing groups can fade over the course as students become more confident and comfortable with CPS. For example, we change groups about 3 - 4 times in the first semester, but fewer times in the second semester. Since students are very sensitive to grades, we change groups only after a class test.

**Figure 2. Why is it better to assign students to groups?**

In our research, we examined the written problem solutions of both homogeneous and mixed-achievement groups (based on past problem-solving test performances). The mixed-performance groups (i.e., a high, medium and lower performing student) consistently performed as well as high performance groups, and better than medium and low performance groups. For example, our algebra-based class was given a group problem that asked for the light energy emitted when an electron moves from a larger to a smaller Bohr orbit. 75 percent of the mixed-performance groups solved the problem correctly, while only 45% of the homogeneous groups solved this problem.

Observations of group interactions indicated several possible explanations for the better performance of heterogeneous groups. For example, on the Bohr-orbit problem the homogeneous groups of low- and medium-performance students had difficulty identifying energy terms consistent with the defined system. They did not appear to have a sufficient reservoir of correct procedural knowledge to get very far on context-rich problems. Most of the homogeneous high performance groups included the gravitational potential energy as well as the electric potential energy in the conservation of energy equation, even though an order-of-magnitude calculation of the ratio of the electric to gravitational potential energy had been done in the lectures. These groups tended to make the problem more complicated than necessary or overlooked the obvious. They were usually able to correct their mistake, but only after carrying the inefficient or incorrect solution further than necessary. For example, in the heterogeneous (mixed-performance) groups, it was usually the medium or lower performance student who pointed out that the gravitational potential energy term was not needed. ["But remember from lecture, the electric potential energy was lots and lots bigger than the gravitational potential energy. Can't we leave it out?"] Although the higher performance student typically supplied the leadership in generating new ideas or approaches to the problem, the low or medium performance student often kept the group on track by pointing out obvious and simple ideas.

In heterogeneous groups, the low- or medium-performance student also frequently asked for clarification of the physics concept or procedure under discussion. While explaining or elaborating, the higher-performance student often recognized a mistake, such as overlooking a contributing variable or making the problem more complicated than necessary. For example, a group was observed while solving a problem in which a car traveling up a hill slides to a stop after the brakes are applied. The problem statement included the coefficient of both static and kinetic friction. The higher performance student first thought that both static and kinetic frictional forces were needed to solve the problem. When the lower-performance student in the group asked for an explanation, the higher-performance student started to push her pencil up an inclined notebook to explain what she meant. In the process of justifying her position, she realized that only the kinetic frictional force was needed. Our results are consistent with the research on precollege students.[3]

# II. What criteria do I use to assign students to groups?

There are three criteria we use to assign students to groups.

1. **Problem-solving Performance.** The most important criterion for assigning students to groups is their problem solving performance based on past problem-solving tests. That is, a three-member group would ideally consist of a higher-performance, a medium-performance, and a lower-performance student. Four-member groups would ideally consist of a high performance, medium-high performance, medium-low performance, and a low-performance student. There are two other "rules of thumb" for assigning students to groups.

2. **Gender.** Our observations indicated that frequently groups with only one woman do not function well, especially at the beginning of class. To be on the safe side, avoid groups with only one woman. We found the difficulty is with the men, not the women (see example at right). Regardless of the strengths of the lone woman, the men in the group tend to ignore her. On the other hand, we found it is dangerous to assign all the students in a class to same-gender groups. The women notice and tend to suspect gender discrimination. Curiously, no one seems to notice when all mixed-gender groups have two women.

> We observed a group, consisting of a lower-performance man, a medium performance man and a high performance woman, having a vigorous discussion about the path of a projectile. The men insisted on a path following the hypotenuse of a triangle; while the woman argued for the correct parabolic trajectory.
>
> At one point, she threw a pen horizontally, commenting as it fell to the floor, "There see how it goes. It does ***not*** go in a straight line!" Even so, she could not convince the two men, who politely ignored her.

3. **English as a Second Language (ESL).** Students from other cultures often have a difficult time adjusting to group work, especially in mixed-gender groups. Their difficulties are exacerbated if English is their second language (ESL). So to be on the safe side, whenever possible we assign ESL students to same-gender groups of three.

## An Example of How to Assign Students to Groups

The following example, for a class of 17 students, describes the steps you can follow to use the criteria to assign students to groups with roles.

Step ①. Calculate the total test score (sum of test scores) for each student. Identify each student's gender (M for male and F for female) and whether English is a second language (ESL). We found it most convenient to use a spreadsheet.

| Name | Gen. | ESL | Test 1 | Test 2 | Total |
|---|---|---|---|---|---|
| Anderson, Max | M | | 62 | 71 | 133 |
| Black, Jennifer | F | | 93 | 85 | 178 |
| Brown, John | M | | 78 | 79 | 157 |
| Edwards, Mark | M | | 54 | 58 | 112 |
| Fairweather, Joan | F | | 73 | 65 | 138 |
| Freedman, Joshua | M | | 86 | 92 | 178 |
| Good, Mary | F | | 100 | 95 | 195 |
| Green, Bill | M | | 79 | 83 | 162 |
| Johnson, Fred | M | | 69 | 70 | 139 |
| Jones, Rachel | F | | 59 | 63 | 122 |
| Nygen, Tan | M | Yes | 84 | 85 | 169 |
| Peterson, Scott | M | | 69 | 61 | 130 |
| Smith, Patricia | F | | 70 | 77 | 147 |
| South, David | M | | 48 | 50 | 98 |
| West, Tom | M | | 52 | 55 | 107 |
| White, Sandra | F | | 55 | 49 | 104 |
| Yurrli, Tamara | F | Yes | 57 | 60 | 117 |

**Step ②.** Sort the class by total test score (highest to lowest). Divide the class into approximate thirds (high performance, medium performance and low performance students). Identify the performance level (Perf.) of each student, as shown below.

| Name | Sex | ESL | Test 1 | Test 2 | Total | Perf. |
|---|---|---|---|---|---|---|
| Good, Mary | F | | 100 | 95 | 195 | Hi |
| Black, Jennifer | F | | 93 | 85 | 178 | Hi |
| Freedman, Joshua | M | | 86 | 92 | 178 | Hi |
| Nygen, Tan | M | Yes | 84 | 85 | 169 | Hi |
| Green, Bill | M | | 79 | 83 | 162 | Hi |
| Brown, John | M | | 78 | 79 | 157 | Hi/M |
| Smith, Patricia | F | | 70 | 77 | 147 | Med |
| Johnson, Fred | M | | 69 | 70 | 139 | Med |
| Fairweather, Joan | F | | 73 | 65 | 138 | Med |
| Anderson, Max | M | | 62 | 71 | 133 | Med |
| Peterson, Scott | M | | 69 | 61 | 130 | Med |
| Jones, Rachel | F | | 59 | 63 | 122 | M/Lo |
| Yurrli, Tamara | F | Yes | 57 | 60 | 117 | Lo |
| Edwards, Mark | M | | 54 | 58 | 112 | Lo |
| West, Tom | M | | 52 | 55 | 107 | Lo |
| White, Sandra | F | | 55 | 49 | 104 | Lo |
| South, David | M | | 48 | 50 | 98 | Lo |

**Step ③.** Within each performance group, sort by gender and ESL. Assign each student to a numbered group (Gr.). First, assign the ESL students to same-gender, mixed performance groups of three (high, medium, and low performance), as illustrated on the next page (bolded group numbers). Assign the remaining students to three- or four-member groups using the mixed-performance and gender criteria.

| Name | Gen. | ESL | Test 1 | Test 2 | Total | Perf. | Gr. |
|---|---|---|---|---|---|---|---|
| Nygen, Tan | M | Yes | 84 | 85 | 169 | Hi | **1** |
| Freedman, Joshua | M | | 86 | 92 | 178 | Hi | 3 |
| Green, Bill | M | | 79 | 83 | 162 | Hi | 4 |
| Brown, John | M | | 78 | 79 | 157 | Hi/M | 5 |
| Good, Mary | F | | 100 | 95 | 195 | Hi | **2** |
| Black, Jennifer | F | | 93 | 85 | 178 | Hi | 4 |
| Johnson, Fred | M | | 69 | 70 | 139 | Med | 5 |
| Anderson, Max | M | | 62 | 71 | 133 | Med | 5 |
| Peterson, Scott | M | | 69 | 61 | 130 | Med | **1** |
| Smith, Patricia | F | | 70 | 77 | 147 | Med | 3 |
| Fairweather, Joan | F | | 73 | 65 | 138 | Med | **2** |
| Jones, Rachel | F | | 59 | 63 | 122 | M/Lo | 4 |
| Edwards, Mark | M | | 54 | 58 | 112 | Lo | **1** |
| West, Tom | M | | 52 | 55 | 107 | Lo | 4 |
| South, David | M | | 48 | 50 | 98 | Lo | 5 |
| Yurrli, Tamara | F | Yes | 57 | 60 | 117 | Lo | **2** |
| White, Sandra | F | | 55 | 49 | 104 | Lo | 3 |

Then sort the groups by group number.

| Name | Sex | ESL | Perf. | Gr. |
|---|---|---|---|---|
| Nygen, Tan | M | Yes | Hi | 1 |
| Peterson, Scott | M | | Med | 1 |
| Edwards, Mark | M | | Lo | 1 |
| Good, Mary | F | | Hi | 2 |
| Fairweather, Joan | F | | Med | 2 |
| Yurrli, Tamara | F | Yes | Lo | 2 |
| Freedman, Joshua | M | | Hi | 3 |
| Smith, Patricia | F | | Med | 3 |
| White, Sandra | F | | Lo | 3 |
| Black, Jennifer | F | | Hi | 4 |
| Green, Bill | M | | Hi | 4 |
| Jones, Rachel | F | | M/Lo | 4 |
| West, Tom | M | | Lo | 4 |
| Brown, John | M | | Hi/M | 5 |
| Johnson, Fred | M | | Med | 5 |
| Anderson, Max | M | | Med | 5 |
| South, David | M | | Lo | 5 |

**Step ④.** Check the groups. If necessary, modify the groups using your knowledge of your students' strengths and weaknesses working cooperatively in groups. For example, suppose Joshua Freedman (Group 3) tries to dominate groups by "railroading" his ideas through a group without listening to other ideas. Patricia Smith and Sandra White are shy and quiet, but work well in congenial groups. You could replace Joshua with another higher-performance male who is listens well and is good at clarifying and explaining ideas, for example Bill Green (Group 4). However, you also have to make sure Joshua is placed in a group that will not let him dominate. Max Anderson has excellent group management skills, so you could put Joshua in Group 5, and move John Brown to Group 4.

If you teach a calculus-based course, you may not have many women in your discussion class, and you cannot put them in the same group all the time. Use your knowledge of their strengths and weaknesses in working cooperatively in groups assign them to groups.

**Step ⑤.** Resort the students by group number, as shown below. Then assign roles to each group member: Manager (M), Skeptic/Summarizer (Sk/Su), and Recorder/Checker (R/C) for three-member groups and Manager (M), Skeptic (Sk), Recorder/Checker (R/C) and Summarizer (Su) for four-member groups. [See Section II for the reasons for assigning roles.]

Use two rules of thumb for the assignment of roles to ***new groups***:

a. Assign the role of Recorder/Checker to the ESL students (see bolded R/C roles in groups 1 and 2 below); and

b. Do not assign the role of Recorder/Checker to the man in a mixed-gender group of three (see italicized R/C role in group 3 below).

| Name | Sex | ESL | Perf. | Gr. | Role |
|---|---|---|---|---|---|
| Nygen, Tan | M | Yes | Hi | 1 | **R/C** |
| Peterson, Scott | M | | Med | 1 | M |
| Edwards, Mark | M | | Lo | 1 | Sk/Su |
| Good, Mary | F | | Hi | 2 | M |
| Fairweather, Joan | F | | Med | 2 | Sk/Su |
| Yurrli, Tamara | F | Yes | Lo | 2 | **R/C** |
| Green, Bill | M | | Hi | 3 | Sk/Su |
| Smith, Patricia | F | | Med | 3 | *R/C* |
| White, Sandra | F | | Lo | 3 | M |
| Black, Jennifer | F | | Hi | 4 | M |
| Brown, John | M | | Hi/M | 4 | Sk |
| Jones, Rachel | F | | M/Lo | 4 | R/C |
| West, Tom | M | | Lo | 4 | Su |
| Freedman, Joshua | M | | Hi | 5 | Sk |
| Johnson, Fred | M | | Med | 5 | Su |
| Anderson, Max | M | | Med | 5 | M |
| South, David | M | | Lo | 5 | R/C |

**Step ⑥.** Make a copy of your group assignments and roles. You can write the assignments on the board before class, or make an overhead to take to class. An example is shown below.

| | | | | | |
|---|---|---|---|---|---|
| **#1** | **M. Edwards** | **Sk/Su** | **#4** | **J. Black** | **M** |
| | **T. Nygen** | **R/C** | | **J. Brown** | **Su** |
| | **S. Peterson** | **M** | | **R. Jones** | **R/C** |
| | | | | **T. West** | **Sk** |

| | | | | | |
|---|---|---|---|---|---|
| #2 | J. Fairweather | Sk/Su | | | |
| | M. Good | M | #5 | M. Anderson | M |
| | T. Yurrli | R/C | | J. Freedman | Sk |
| | | | | F. Johnson | Su |
| #3 | B. Green | Sk/Su | | D. South | R/C |
| | P. Smith | M | | | |
| | S. White | R/C | | | |

**Step ⑦.** Each subsequent time the same group works together, their roles **MUST ROTATE.** This is particularly important for the computer labs. One way to accomplish this is to list the group members with roles on the board each session, as shown above. You can use a spreadsheet to keep track of the roles you have assigned to each group member. An example is shown below.

| Name | Gr. | DS 10/15 | Lab 10/20 | DS 10/22 | Lab 10/27 | DS 10/29 | Lab 11/3 |
|---|---|---|---|---|---|---|---|
| Nygen, Tan | 1 | R/C | M | Sk/Su | R/C | M | Sk/Su |
| Peterson, Scott | 1 | M | Sk/Su | R/C | M | Sk/Su | R/C |
| Edwards, Mark | 1 | Sk/Su | R/C | M | Sk/Su | R/C | M |
| Good, Mary | 2 | M | Sk/Su | R/C | M | Sk/Su | R/C |
| Fairweather, Joan | 2 | Sk/Su | R/C | M | Sk/Su | R/C | M |
| Yurrli, Tamara | 2 | R/C | M | Sk/Su | R/C | M | Sk/Su |
| Green, Bill | 3 | Sk/Su | R/C | M | Sk/Su | R/C | M |
| Smith, Patricia | 3 | R/C | M | Sk/Su | R/C | M | Sk/Su |
| White, Sandra | 3 | M | Sk/Su | R/C | M | Sk/Su | R/C |
| Black, Jennifer | 4 | M | Sk | R/C | Su | M | Sk |
| Brown, John | 4 | Sk | R/C | Su | M | Sk | R/C |
| Jones, Rachel | 4 | R/C | Su | M | Sk | R/C | Su |
| West, Tom | 4 | Su | M | Sk | R/C | Su | M |
| Freedman, Joshua | 5 | Sk | Su | M | R/C | Sk | Su |
| Johnson, Fred | 5 | Su | M | R/C | Sk | Su | M |
| Anderson, Max | 5 | M | R/C | Sk | Su | M | R/C |
| South, David | 5 | R/C | Sk | Su | M | R/C | Sk |

# Footnotes

1 Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. *American Journal of Physics*, 60, 627-636.

[2] Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, 60, 637-644.

[3] Johnson, D. W. and Johnson, R. T. (1989). Cooperation and Competition: Theory and Research, Edina, MN: Interaction.

# III. How Can I Structure Group Work to Maintain Well-functioning Groups?

With structure and guidance, most students learn to function relatively well in groups. Occasionally, a group may exhibit one of the following dysfunctional behaviors:

- Less able members sometimes "leave it to John" to solve the group problem, creating a **free-rider** effect.
- At the same time, more able group members expend decreasing amounts of effort to avoid the **sucker** effect.
- High ability group members may be deferred to and take over leadership roles in ways that benefit them at the expense of the other group members (the **rich-get-richer** effect).
- Groups with no natural leaders may avoid conflict by "voting" rather than discussing an issue (**conflict avoidance** effect).
- Group members argue vehemently for their point of view and are unable to listen to each other or come to a group consensus (**destructive conflict** effect).

This section gives several suggestions to help you maintain well-functioning groups.

## Seating Arrangement

In discussion section, make sure the seats are arranged so students are facing each other, "knee-to-knee”. [See Figures 3 and 4 on the next page.] This seating arrangement makes it much harder for a student to remain uninvolved with a group. If you observe students sitting in a row, or one student sitting "outside" a pair, go over to the group and make them stand up and rearrange their chairs.

In labs, make sure students are standing or sitting so they are all facing each other. In computer labs, make sure all students can see the screen. If you observe a group with one member doing all the work or one member left out, go over to the group and make them rearrange their seating/standing.

## Group Role Assignment and Rotation

Many different roles can be assigned for different types of tasks. For problem solving, we assign planning and monitoring roles that students have to assume when they solve challenging problems *individually* --Manager, Checker/Recorder, and Skeptic/Summarizer. When students solve problems, they have to be an executive *manager*, organizing a plan of action to solve the problem, and making sure they don't loose track of where they are and what they need to do next. At the same time, they have be a *recorder* of the solution. During this process, they must *check* their solution and make sure it *explains* what they did (to a knowledgeable reader) in a logical and organized fashion.

Figure 1. Bad Example of Seating Arrangement

Figure 2. Good Example of Seating Arrangement

Figure 3. Research on Assigning and Rotating Group Roles.

Our[1] observations of group interactions after we assigned roles indicated that the number of dysfunctional (e.g., one student dominates; students cannot resolve a difference of opinion) at any given time decreased from about 40% (2 in 5 groups) to about 10 - 20% (less than 1 out of every 5 groups). With fewer dysfunctional groups, an instructor has more time for appropriate and timely intervention to coach physics. This optimizes the learning of *all* students. Our interviews confirmed that students in groups with assigned and rotated roles were more comfortable with their group interactions, particularly at the beginning of the course. Our results are consistent with the research on precollege students.[2]

Finally, they have to continually be *skeptical*, asking themselves questions about each step -- "Am I sure that this is the right physics?" "This doesn't seem right. What have I forgotten to take into account?" A description of the group roles you will use is shown on the next page.

In *well functioning groups*, members share the roles of manager, checker, explainer, skeptic and conciliator (who solves conflicts and strives to minimize interpersonal conflict), and role assumption usually fluctuates over time. Students in these groups do not need to be reminded to "stick to their roles." But students in Students in dysfunctional groups *cannot* learn, and the result is very disgruntled students.

**The purpose of the roles is to give you a structure to help you intervene with groups that are not functioning well or that are having difficulty with physics** (see Section III, pages // to //). The roles help reduce the number of dysfunctional groups in several ways.

`Individual Responsibility.` At the beginning of an introductory class, some students have never participated in cooperative problem solving and do not know what they are supposed to do. The roles remind them of appropriate individual actions in a group.

`Optimal Learning.` Assigning and rotating roles helps to avoid both dominance by one student (the person with the pencil or keyboard has the real "power" in the group) and the free-rider effect. Assigning roles allows students to practice behavior that may not be natural or even socially acceptable. For example, “I don’t want to be bossy, but I am the manager. Let’s move on to . . .” In addition, we initially had some students who were too polite to disagree openly with the ideas of other group members (conflict avoidance). The role of “Skeptic” allowed these students a socially acceptable way to disagree. The roles also help groups that tend towards destructive conflict.


Remember

Remember the 2nd Law of Education: Don’t change course in midstream. It is better to impose a structure early then fade. This means it is very difficult to assign roles when you finally discover that you need them. As students become more comfortable and competent with CPS, the group roles slowly and naturally "fade" away from students' minds, except when you intervene with an occasional dysfunctional group.

## Group Roles

In your discussion section for this course, you will be working in **cooperative** groups to solve written problems. To help you learn the material and work together effectively, each group member will be assigned a specific role. Your responsibilities for each role are defined on the chart below.

| ACTIONS | WHAT IT SOUNDS LIKE* |
|---|---|
| **MANAGER**<br>DIRECT THE SEQUENCE OF STEPS.<br>KEEP YOUR GROUP "ON-TRACK."<br>MAKE SURE EVERYONE IN YOUR GROUP PARTICIPATES.<br>WATCH THE TIME SPENT ON EACH STEP. | *"First, we need to draw a picture of the situation."*<br>*"Let's come back to this later if we have time."*<br>*"Chris, what do you think about this idea?"*<br>*"We only have 5 minutes left. Let's finish the algebra solution.* |
| **RECORDER/CHECKER**<br>ACT AS A SCRIBE FOR YOUR GROUP.<br>CHECK FOR UNDERSTANDING OF ALL MEMBERS.<br>MAKE SURE ALL MEMBERS OF YOUR GROUP AGREE WITH EACH THINK YOU WRITE.<br>MAKE SURE NAMES ARE ON SOLUTION. | *"Do we all understand this diagram I just finished?"*<br>*"Explain why you think that . . . ."*<br>*"Are we in agreement on this?"*<br>*"Here, sign the problem we just finished!"* |

| **SKEPTIC/SUMMARIZER** | |
|---|---|
| HELP YOUR GROUP AVOID COMING TO AGREEMENT TOO QUICKLY.<br>MAKE SURE ALL POSSIBILITIES ARE EXPLORED.<br>SUGGEST ALTERNATIVE IDEAS.<br>SUMMARIZE (RESTATE) YOUR GROUP'S DISCUSSION AND CONCLUSIONS.<br>KEEP TRACK OF DIFFERENT POSITIONS OF GROUP MEMBERS AND SUMMARIZE BEFORE DECIDING. | *"What other possibilities are there for …?"*<br>*"I'm not sure we're on the right track here. Let's try to look at this another way. . . ."*<br>*"Why?"*<br>*"What about using . . . . instead of . . . . ?*<br>*"So here's what we've decided so far. ."*<br>*"Chris thinks we should . . . . , while Pat thinks we should . . . ."* |

Figure 4. Research on Assigning and Rotating Group Roles.

When students were given a chance to discuss their group's functioning, their attitude about group problem solving improved. There was also a sharp decrease in the number of students who visited instructors during office hours to complain about their group assignment. In addition, groups that were not functioning well improved their subsequent effectiveness following these discussions. For example, in groups with a dominant student, the other group members were more willing to say things like: Hey, remember what we said last week. Listen to Kerry. She's trying to explain why we don't need all this information about the lunar lander's descent." In groups that suffered from conflict avoidance, there were comments like: "Oops! I forgot to be the skeptic. Let's see. Are we sure friction is in this direction. I mean, how do we know it's not in the opposite direction?" As usual, this result was consistent with the research on precollege students.[3]

## Random Calling on Students

In both discussion sections and lab, randomly call on individual students in a group to present their group's results. **This person is *not* usually the Recorder/Checker for the group**. In the beginning of the course, you can call on the individuals who seem most enthusiastic or involved. After students are familiar with group work, you can either call on the Skeptic/Summarizers or Managers, or call on individuals who seemed to be the least involved. This technique helps avoid both dominance by one student and the free-rider effect.

## Group Processing

One of the elements that distinguish traditional groups from cooperative groups is structuring occasional opportunities for students to discuss how well they are solving the problems together and how well they are maintaining effective working relationships among members. For this purpose, you could use the *Group Functioning Evaluation* form shown on the next page. After the group has discussed and completed the evaluation, the instructor spends a few minutes in a class discussion of the answers to Question 6, so students can consider a wider range of ways groups could function better. Common answers include: "Come better prepared; Listen better to what people say; Make better use of our roles (e.g., "Be sure the Manager watches the time so we can finish the problem." or "Be sure the Skeptic doesn't let us decide too quickly.").

At the beginning of the first semester, we recommend doing group processing *every* class session. After two to three weeks (i.e., after students have worked in two different groups), you can reduce group processing to about once every two to three weeks, as it seems necessary (usually the first time new groups are working together).

## Group Evaluation Sheet

**Date:** ________________ **Group #:** _____

Complete the following questions as a team.

| | Low | | | | High |
|---|---|---|---|---|---|
| 1. Did all the members of our group contribute ideas? | 1 | 2 | 3 | 4 | 5 |
| 2. Did all the members of our group listen carefully to the ideas of other group members? | 1 | 2 | 3 | 4 | 5 |
| 3. Did we *encourage* all members to contribute their ideas? | 1 | 2 | 3 | 4 | 5 |

**4.** What are two **specific** actions we did today that helped us solve the problem?

**5.** How did each of us contribute to the group's success?

**6.** What is a specific action that would help us do even better next time?

**Group Signatures:**

**Manager**: ________________________________.

**Skeptic**: ________________________________.

**Recorder/Checker**: ________________________________.

**Summarizer**: ________________________________.

## Grading

The Zeroth Law of Education is:

0th Law

**If you don't grade for it, students won't do it.**

One consequence of the Zeroth Law of Education is that your students will work more effectively in cooperative groups when group problem solutions are occasionally graded. Group problem solutions are usually only 10% - 15% of a student's grade in the course. There are many ways that your team may grade the group problem solutions. For example, your team might assign 10% - 15% of each student's grade to a fixed number of group problem solutions. That is, groups occasionally turn in one problem solution for grading, and each group member gets the same grade for the group solution.

In some teams, each test has a group part and an individual part. The first part of the test is a group problem that students complete in their discussion sections. The following day students complete the individual part of the test. The group problem is usually about 25% of a student's total score for each test. When the final exam is added, the group problems are only about 15% of their total test scores. When other parts of the grade are added (e.g., individual laboratory reports), group problems are 10% or less of the students' course grade. [The advantage of this presentation of grading lies in the way students interpret their test scores. When groups are well managed, the highest score that students receive on a test is almost always for the group problem, which is also the most difficult problem on the test.[1] This reinforces the advantages of cooperative-group problem solving.]

To avoid the free-rider effect, your team may want to set the rule that group members absent the week before the graded group problem (i.e., s/he did not get to practice with her/his group) cannot take part in solving the graded group problem. Towards the end of the first semester, you could let the rest of the group members decide if the absent group member can take part in solving the graded group problem.

To encourage students to work together in lab, your team could decide that each member of the group receives bonus points if all group members earn 80% or better on their individual lab problem reports.

# Footnotes

[1] Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, 60, 637-644

[2] Johnson, D. W. and Johnson, R. T. (1989). Cooperation and Competition: Theory and Research, Edina, MN: Interaction.

# IV. How Do I Coach Students During Group Work?

There are two important instructor actions involved in efficient and timely coaching of groups while they are working to solve a problem:

- monitoring *all* groups and diagnosing their difficulties; and
- intervening and coaching the groups that need the most help.

Coaching groups that are solving problems is similar to triage in a medical emergency room. When there are more patients than available doctors, doctors first *diagnose* what is wrong with each patient to decide which patients need immediate care and which can wait a short time. The doctors then treat the patient with the most need first, then the second patient, and so on. Similarly, with CPS the instructor needs to first diagnose the "state of health" of each group by observing and listening to each group (without interacting with the groups). With CPS, you diagnose:

- what physics concepts and problem-solving procedures each group does and does not understand; and
- what difficulties group members are having working together cooperatively.

As with medical triage, your next step is to intervene with the group that is in the *worst* state of health -- the group that is having the most difficulty with the physics or with group functioning.

This section contains recommendations of how to monitor and coach groups

## Monitor and Diagnose

The following steps are helpful to monitor and diagnose the progress of *all* groups:

`Step 1.` Establish a circulation pattern around the room. Stop and observe each group to see how easily they are solving the problem and how well they are working together. Don't spend a long time observing any one group. Keep well back from students' line of sight so they don't focus on you.

`Step 2.` Make mental notes about each group's difficulty, if any, with group functioning or with applying physics principles to the problem solution, so you know which group to return to first.

Step 3. If several groups are having the **same** difficulty, you may want to stop the whole class and clarify the task or make additional comments that will help the students get back on track. For example, there is a tendency for students to immediately try to plug numbers into equations each time new physics principles are introduced. If about half of your groups are doing this, stop the whole class. Remind your students that the first step in problem solving is a thorough analysis of the problem *before* the generation of mathematical equations.

If you begin intervening too soon (without first diagnosing all groups), it is not fair to the last groups. By the time you recognize that all groups may have the same difficulty, the last groups will have wasted considerable time.

## Intervene and Coach

From your observations (circulation pattern), decide which group is obviously struggling and needs attention most urgently. Return to that group and watch for a few minutes to diagnose the exact nature of the problem, and then ***join the group at eye level.*** You could kneel down or sit on a chair, but do not loom over the students.

If you spend a long time with this group, then circulate around the room again, noting which group needs the most help. Keep repeating the cycle of (a) circulate and diagnose, (b) intervene with the group that needs the most help.

In *well functioning groups*, members share the roles of manager, checker, explainer, skeptic and conciliator (who solves conflicts and strives to minimize interpersonal conflict), and role assumption usually fluctuates over the time students are solving a problem. Students in these groups do not need to be reminded to "stick to their roles." For dysfunctional groups, however, group roles are an important part of *all* intervention strategies. For example, one way to intervene with a dysfunctional group (e.g., a dominant student, one person working alone) is to ask: "Who is the manager (or skeptic/summarizer, or recorder/checker, depending on the dysfunctional group behavior)? What should you be doing to help resolve this problem?" If the student does not have any suggestions, then model several possibilities.

# Coaching Dysfunctional Groups

## First Few CPS Sessions.

In the first CPS sessions, students with no prior experience with cooperative learning do not understand their role in a group co-construction of a problem solution. There is a tendency to solve problems individually, especially if there is a disagreement within the group. The three examples below illustrate some common difficulties and possible interventions for the first CPS sessions.

**Example 1: Individual Problem Solving.** You observe a group in which the members are not talking to each other, but solving the group problem individually.

Say something like: "I notice that you are solving the problem individually, not as a group. Who is the Recorder/Checker? You should be the only person writing the solution. Manager and Skeptic/Summarizer put your pencils away and work with the Recorder/Checker to solve the problem."

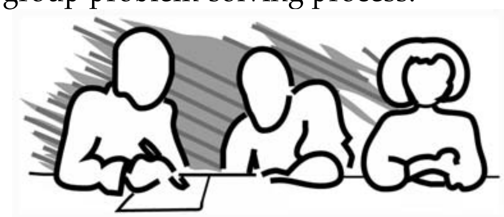
If necessary, make the students rearrange their chairs so they can all see what the Recorder/Checker is writing. If the students persist in solving the problem individually and only then return to the group to compare answers, explain again that they should be solving the problem together. Take the pencils from the Manager and Skeptic (return them at the end of class), and have the group read the Group Role sheet again. Do not leave until they have started solving the problem together.

**Example 2: A Lone Problem Solver.** You observe a group in which two members, including the Recorder/Checker, are working together, but one member is working alone to solve the problem (hereafter called "the loner." First, try to determine why the loner is solving the problem alone. Say something like: "I notice that while two of you are working together, you (loner) appear to be solving the problem by yourself. What are each of your group roles? Why are you (loner), as the group Manager (or Skeptic/Summarizer) solving the problem by yourself?"

Frequently, the loner will sheepishly mumble something about not being used to working in a group. This individual may need only a gentle reminder to give group work a try. Ask the Recorder/Checker to explain to the loner what they have done so far to solve the problem. If necessary, make the students rearrange their chairs so they can all see what the Recorder/Checker is writing.

Occasionally, a loner is more adamant about needing to solve the problem alone before talking with the group. Maintain a sympathetic attitude, but explain to the loner that research shows that *all* students learn much more about physics and problem-solving procedures when they construct problem solutions together. This is why you work in groups in this class. Although it may seem difficult at first, s/he should try it. Tell the individual to put his pencil away and ask the Recorder/Checker to explain to the loner what they have done so far to solve the problem.

`Example 3: A Non-participant.` You observe a group in which one member does not appear to be engaged in the group problem-solving process.



Try to determine why the student appears to be disengaged. For example, if the students are sitting in a row and not facing each other, have the students to get up and rearrange the chairs so they sit facing each other. Ask the student to explain what the group is doing and why. [This emphasizes the fact that **all** group members need to be able to explain each step in solving a problem.] If the student can describe what the group is doing and why, then s/he may be a quiet student who pays attention, but does not speak as often as the others. You do not need to intervene further.

If the student does not have a clear idea of what the other group members are doing, s/he may be what is called a "free-rider" -- a person who leaves it to others to solve the problem. Ask the free rider: What is your group role? What should you be doing to help your group solve this problem?" [If necessary, have the free rider read the role description from the Group Role sheet.] If the free rider is not the Manager, ask the Manager what s/he could do to make sure everyone, including the free rider, participates in solving the problem.

## Later CPS Sessions.

With appropriate structure (see Section II) and coaching, most students learn to function in groups relatively well. Occasionally, however, a group may exhibit one of the following dysfunctional behaviors.

- Lower-achievement members sometimes "leave it to John" to solve the group problem, creating a *free-rider* effect. At the same time, higher achieving group members may expend decreasing amounts of effort to avoid the *sucker* effect. This sucker effect is unusual when group problems are graded occasionally.

- Higher-performance group members may be deferred to and take over leadership roles in ways that benefit them at the expense of the other group members (the *dominant student* or *the rich-get-richer* effect).
- Groups with no natural leaders may avoid conflict by "voting" or not making any decision rather than discussing an issue (*conflict avoidance* effect).
- Group members argue vehemently for their point of view and are unable to listen to each other or come to a group *consensus (destructive conflict effect*).

The last section included an example of how to intervene in a group with a "free-rider." The two examples below suggest how to coach groups with a dominant students or a conflict.

Example 1: Dominant Student.
You observe a group in which one member is doing almost all of the talking, while the other members appear somewhat disengaged and lethargic.

In this case, all members are failing in their roles. First tell the group: "I notice that one person appears to be doing all the talking in this group." Then ask: Manager, what could you be doing to make sure that all members of your group contribute their ideas?" If the manager has no ideas, then either have the group read their *Group Role* sheet (early in course) or make a suggestion, such as: "For each step in your problem solving process, ask each member of your group what they think." Point to a specific part of the group's solution and model some specific questions the Manager could ask.

Repeat this procedure with each group member. Ask: "Checker/Recorder, what could you be doing to make sure that all members understand and can explain everything that is written down?" [Periodically ask each member if they understand and agree with everything written down. Point to part of the group's solution and model some specific questions.] Ask: "Skeptic, what could you be doing to make sure that all possibilities and alternative ideas are being considered by the group?" [Be sure to ask for a justification for an idea, and suggest alternative ideas. Point to specific parts of the group's solution and model specific questions the skeptic could ask.]

Example 2: Conflict Avoidance or Destructive Conflict.
You observe a group that is struggling to come to a decision, but does not appear to have any strategy to reach a decision (conflict avoidance) or a group that is arguing loudly, but does not appear to be resolving their

conflict (destructive conflict). Ask the group: "Who is the Skeptic/Summarizer (or Summarizer in a four-member group)? I noticed that you are having difficulty deciding . . . . . Summarizer, what could you be doing to help the group come to a decision that is agreeable to all of you? If the Summarizer has no idea, then either have the group read the *Group Role* sheet again (early in course) or give some suggestions, such as: "Stop and summarize your different ideas. Then discuss the merits of each idea. For example, you could . . . ." The specific suggestions you give will depend on the exact nature of the decision.

## Coaching Groups with Physics Difficulties

As the number of dysfunctional groups decreases, you will spend more of your time coaching groups that are having difficulty applying physics concepts and principles to solve the problem. The general approach to coaching is to give a group just enough help to get them back on track, then leave. That is, spend as little time as possible with a group, then go to the next group that needs help, and so on. Below are some general guidelines for coaching groups with physics difficulties.

`Step 1.` Before you intervene, listen to the discussion in a group for a few minutes and look at what the checker/recorder is drawing and writing. Diagnose the group's specific difficulty. A checklist of common student difficulties is shown in Figure 6 on the next page

`Step 2.` Based on the nature of the group's difficulty, decide *how* to begin your coaching of the group. There are two general coaching approaches, depending on whether you can point to the difficulty on the group's answer sheet.

- Use Group Roles. Point to something on the answer sheet and state the general nature of the difficulty or error. Then ask: "Then ask: "Who is the manager (or skeptic/summarizer, or recorder/checker)? What could you be doing to help resolve this problem?" If the student/group does not have any suggestions, then model several possibilities.
- General Questions. If you can not point to something specific written on the group's answer sheet, begin by asking the group some general questions to find out what they are thinking, such as: (a) What are you doing? (b) Why are you doing it? and (c) How will that help you?

`Step 3.` Based on the answers you get to your initial question(s), ask additional questions until you get the group thinking about *how* to correct their difficulty. That is, try to give a group just enough help to get them back on track, then leave. Check back with the group later to see if your coaching was sufficient for the group to discuss the difficulty and get back on track.

Figure /./

## Analyze the Problem

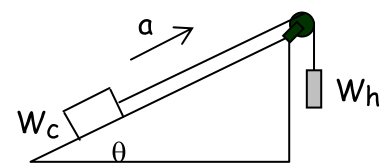
1. **Picture or Diagram is missing, misleading, or inaccurate**
    a. picture/diagram missing
    b. picture/diagram missing important objects or interactions
    c. picture/diagram includes spurious (irrelevant) objects or interactions
    d. other incorrect diagrammatic translations of problem information
2. **Relevant variables not assigned and clearly labeled**
    a. many important variables are not defined
    b. defined variables are not clearly distinguished from each other
3. **Approach invalid, too vague, or missing**
    a. application of principles is inappropriate
    b. misunderstanding of fundamental principle
    c. simplifying approximations not stated or inappropriate
4. **Necessary fundamental principles missing**
5. **Incorrect or invalid statement of known values or assumptions**
6. **Incorrect assertion of general relationships between variables**
    a. application of principles to inappropriate parts of the problem
    b. incorrectly assumed relationship between unknown variables, such as $T_1=T_2$.
    c. overlooked important relationship between unknown variables, such as $a_1=a_2$.
    d. misunderstanding of a physics concept
7. **Incorrect statement of target variable or no target stated**
    a. target variable doesn't correspond to question in Approach
    b. does not explicitly state target variable
    c. wrong target
8. **Major misconception**

### PLAN THE SOLUTION

9. **Poor use of the physics description to generate a plan**
    a. physics description was not used to generate a plan
    b. inappropriate equation(s) was introduced
    c. undefined variables used in equations
10. **Improper construction of specific equations**
    a. inappropriate substitution of variables into general equations
    b. numerical values were substituted too soon
11. **Solution order is missing or unclear**
    a. there is no clear logical progression through the problem
    b. solution order can't be understood from what is written
12. **Plan cannot be executed**
    a. there are not enough equations (usually an equation is needed from analysis of problem situation)
    b. a relationship was counted more than once

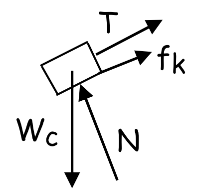
# Examples of Coaching Using Group Roles

Suppose your students are solving a modified Atwood machine problem, as shown in the diagram at right. As part of the solution, students must find the tension of the rope. Below are some examples of a coaching technique that uses group roles.



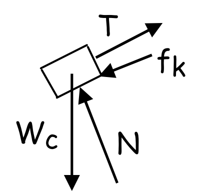

## Example 1: Misunderstanding of Physics Concept

You observe that a group has drawn the frictional force in the wrong direction on their diagram. Point to the diagram: "There is something wrong with one of the forces in this diagram. Skeptic, what questions could you ask about each of these forces?" When the skeptic has responded (e.g., Does each interaction result in a push or a pull on the carton? In what direction?), then leave the group.




## Example 2: Improper Construction of Specific Equation

You observe that a group has drawn a correct force diagram, but there is a sign wrong for the frictional force in their Newton's 2nd Law component equation:




$$\sum F_x = ma_x$$

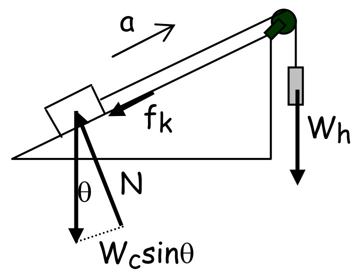
$$T - W_c \sin\theta - \mu W_c \cos\theta = \frac{W_c}{g} a$$

Point to the force diagram *and* the equation: "You have made a mistake in translating from your diagram to this equation. Skeptic, what questions could you ask about each translation?" When the group has responded (i.e.,?), then leave the group.

## Example 3: Diagram Missing

You observe that a group has not drawn a separate force diagram. But their 2nd Law equation is correct except for the wrong sign for the frictional force. Point to the equation: "There is a simple mistake in this equation. Manager, what do you think is an important part of analyzing a problem that could have led to a mistake in this equation?" When the group has responded with "a force diagram," leave the group.

Example 4: Major Misconception




You observe a group that has not drawn separate force diagrams for both the carton and the hanging weight. Instead, they sketched some forces on the picture, as shown at right. In addition, they did not start their equations with Newton's Second Law in it's general form, $\Sigma F_x = ma_x$. Instead, the first equation is:

$$T = W_h - f_k - W_c \sin\theta$$
$$= W_h - \mu W_c \cos\theta - W_c \sin\theta$$

Equations of this type often indicate a misconception about Newton's 2nd Law. We have found that about 20% of students in the calculus-based course solve Newton's Law problems by setting the unknown force (tension in this problem) equal to the sum of the known forces (in this case all the other forces acting on the carton and the hanging weight). [In addition, about 20% solve Newton's Law problems by setting the unknown force (e.g., tension) equal to "ma," or by setting the sum of the forces equal to zero even when there is an acceleration.]

Point to the equation: "This equation is wrong. Checker/recorder (or Summarizer), could you describe how your group arrived at this equation?" Specific follow-up questions will depend on the response of the group. If you have Newton's Second Law ($\Sigma F_x = ma_x$) on the Problem & Information sheet, then you could point to this equation and ask the group what this equation means. Finally, you may need to coach the group through drawing free-body force diagrams for each object (carton and hanging weight).

## General-Questions Coaching Technique

Sometimes, by the time you get to a group, students are having several interrelated problems. Sometimes it is impossible to identify a specific error. Your intervention with this group will take longer. You can start coaching by asking the group: (a) What are you doing? (b) Why are you doing it? and (c) How will that help you? This often provides you with enough information to diagnose the problems and deal with them one at a time. Always try to ask questions, rather than give answers.