Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups

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A supportive environment based on cooperative grouping was developed to foster students' learning of an effective problem-solving strategy. Experiments to adapt the technique of cooperative grouping to physics problem solving were carried out in two diverse settings: a large introductory course at state university, and a small modern physics class at a community college. Groups were more likely to use an effective problem-solving strategy when given context-rich problems to solve than when given standard textbook problems. Well-functioning cooperative groups were found to result from specific structural and management procedures governing group members' interactions. Group size, the gender and ability composition of groups, seating arrangement, role assignment, textbook use, and group as well as individual testing were all found to contribute to the problem-solving performance of cooperative groups.

I. INTRODUCTION

This is the second of two articles which reports investigations of an instructional approach for the effective teaching of physics problem solving. The approach combines explicit teaching of a problem-solving strategy with a supportive environment for helping students implement the strategy. The prescribed problem-solving strategy is based on the nature of effective (or "expert") problem solving in physics.[1,2] This strategy, which is described in detail in the first article,[3] emphasizes the qualitative description and analysis of the problem situation, planning a solution before the mathematical manipulation of equations, and checking and evaluating the answer to see if it makes sense. Cooperative groups were used to provide a supportive environment in which students practiced using the problem-solving strategy.

The results reported in the first article indicate that the instructional approach is effective in improving the individual problem-solving performance of all students in a large introductory physics course. The success of the approach is dependent, however, on two factors. The first factor is the type of problems students are given to solve. The problems must discourage the use of novice problem-solving strategies and promote the use of the more effective, prescribed strategy. The second factor is the formation and maintenance of well-functioning cooperative groups. Unlike traditional groups, cooperative groups are carefully structured and managed to maximize the active and appropriate participation of all students in the group.[4] In well-functioning groups, students share their conceptual and procedural knowledge in the joint construction of a problem solution, so that all students are actively engaged in the problem-solving process and differences of opinion are resolved in a reasonable manner.

Most of the previous research in cooperative grouping has been done with precollege students.[5-7] This article reports the results of investigations at the college level to answer the following questions:

1. What type of physics problems promotes students' use of an effective problem-solving strategy?
2. What structural and management procedures result in well-functioning cooperative groups for physics problems solving?
3. Is the instructional approach adaptable to different settings?

II. PROCEDURE

For the past 3 years, we have been experimenting with ways to adapt and modify some general recommendations for cooperative grouping[8] to the specific context of teaching physics problem solving at the college level. A standard formative evaluation procedure[9] was used to monitor, modify, and adjust the structure and management of the problem-solving groups. Observations of student interactions were made of groups solving different types of problems, groups with different structures, and groups with different management procedures. The groups were observed by the instructors and other science educators, and a subsample of groups were videotaped for later analysis. Group problem solutions were photocopied so the problem-solving performance of groups with different problem types, structures, or management procedures could be examined and compared. A random sample of groups was interviewed, and questionnaires which asked for students' perceptions of their cooperative group experiences were collected from all students. Approximately 400 students participated in this study. The evaluation procedure yields a large and rich collection of varied data. For the sake of brevity, we have not described all the types of data collected in each investigation.

The experiments were conducted in two different settings, a large state university and a community college. The algebra-based, introductory physics course for nonmajors at the University of Minnesota enrolls about 120 students per quarter and uses cooperative problem-solving groups in recitation sections of about 18 students. The recitation sections are taught by graduate teaching assistants (TAs) who receive training in cooperative-grouping in the quarter prior to the course.[10] The TAs also conducted laboratories with the same groups of students. At Normandale Community College, cooperative groups are used in a sophomore-level modern physics course for physics and pre-engineering majors. In this course, which enrolls 10–12 students, the cooperative problem-solving groups are led by the instructor (MH). In both educational settings, the lecturer (not the TAs) outlined the development of the physics concepts and modeled the prescribed problem-solving strategy.

The first two sections below report the results of investigations in the large introductory physics course. The following section reports the results of investigations in the smaller modern physics classes at a community college. The final section summarizes our current approach for structuring and managing cooperative problem-solving groups.

III. DESIGNING PHYSICS PROBLEMS TO PROMOTE EFFECTIVE PROBLEM SOLVING

The determination of the types of physics problems that are most effective in promoting students' use of the prescribed problem-solving strategy was accomplished in three phases. First, we examined student problem solutions and group interactions for standard textbook problems and characterized the typical novice strategy for solving these problems. Second, we compared textbook problems with real-world problems to determine (a) the characteristics of textbook problems that encourages the continued use of the novice strategy, and (b) the characteristics of real problems that require the use of an expert strategy. Finally, we designed "context-rich" problems based on the structure of real problems and tested the effectiveness of these problems in promoting the application of the prescribed strategy. The results of each of these phases are described below.

A. Standard textbook problems

The first problems given to cooperative groups in the introductory physics course were standard, end-of-chapter textbook problems such as the following:

> A 5.0-kg block slides 0.5 m up an inclined plane to a stop. The plane is inclined at an angle of 20° to the horizontal, and the coefficient of kinetic friction between the block and the plane is 0.60. What is the initial velocity of the block?

While solving these problems, the group discussions tended to revolve around "what formulas should we use" rather than "what physics concepts and principles should be applied to this problem." Figure 1 is an illustration of a typical group solution for this problem. The students in this group did not begin with a discussion and analysis of the forces acting on the block in this situation. Instead, they attempted to recall the force diagram and formulas from their text, which were for a block sliding *down* an inclined plane. Consequently, their solution has the frictional force in the wrong direction and the force equation has a sign error. The students did not plan a solution before the mathematical manipulation of equations, but haphazardly plugged numbers into formulas until they had calculated a numerical answer. Their conversations concerned finding additional formulas that contained the same symbols as the unknown variables. ("Can't we use this distance formula [$x = vt$]? It has v and t in it.") They did not discuss the meaning of the symbols or formulas, and they incorrectly combined a formula containing an instantaneous velocity ($v = at$) with a formula containing an average velocity ($x = \bar{v}t$) to calculate the initial velocity of the block.

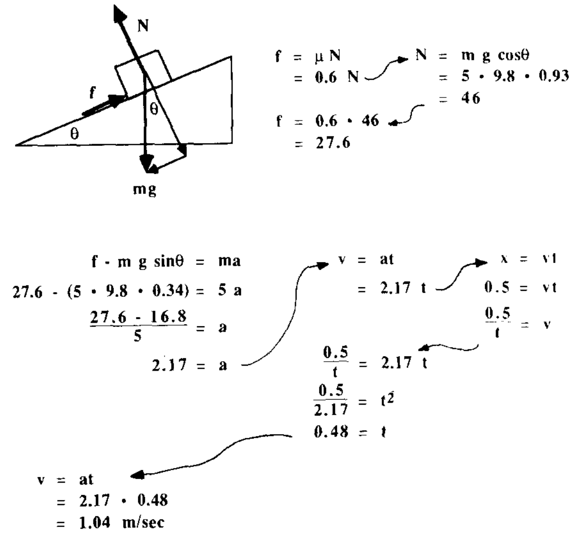


Fig. 1. A typical incorrect solution of a group for a standard textbook problem. The arrows show the progression of the mathematical solution.

From observations, interview data, and the examination of group problem solutions, we estimated that about two-thirds of the groups used this "formulaic" problem-solving approach instead of the prescribed strategy that was taught by the lecturer. We concluded that standard textbook problems were not effective in promoting the type of group discussions that would help the students become better problem solvers.

B. A comparison of textbook and real problems

An analysis of standard textbook problems suggested several characteristics that encourage students' continued use of the formulaic strategy, despite the instructor's effort to teach a more effective strategy. Typically, textbook problems refer to idealized objects and events (e.g., a block sliding on an inclined plane) that have no connection with the student's reality. This would seem to reinforce the student's predilection to memorize sets of formulas and techniques (algorithms), each of which applies to a very specific idealized object or situation (e.g., inclined plane problems are different from circular motion problems).[11,12] In addition, the unknown variable is specified in the last sentence and all the variables needed to solve the problem are concisely reported in consistent units. This feature appears to reinforce a strategy of selecting the memorized formulas that contain all the given variables and then plugging in numbers until a combination is found that gives an answer. For textbook problems such as the inclined-plane problem shown above, there is no need for the student to consider the units of the quantities involved or solve the problem with reference to physical variables (algebraically) before doing arithmetic.

On the other hand, in real-world problems there is a motivation or reason for wanting to know about actual objects or events with which the students are familiar. Before mathematical manipulation of formulas can begin, the problem solver must decide (1) which specific variable(s) would be useful to answer the question, (2) what physics concepts and principles could be applied to determine that variable, (3) what information would be needed, and (4) where or how that information could be obtained or estimated. That is, the appropriate physics concepts and principles must, of necessity, be decided upon early in the problem-solving process in order to organize the gathering of pertinent information. We hypothesized that solving real problems emphasizes the application of physics concepts and principles, because they force these decisions to be made. Most textbook problems have removed the necessity of making decisions, so solving physics problems appears to the students to be an exercise in algorithmic applications.

C. Design and testing of "context-rich" problems

To encourage students to practice using the prescribed problem-solving strategy, "context-rich" problems were designed that have many characteristics in common with real problems. Examples of these problems are given in Table I. Context-rich problems are short stories that include a reason (if sometimes far-fetched or humorous) for calculating specific quantities about real objects or events. In addition, they may have one or more of the following characteristics:

1. The problem statement does not always specify the unknown variable (e.g., Will this design for the lunar lander work?); the students must decide upon an appropriate target variable that will answer the question.
2. More information may be available than is needed to solve the problem; the appropriate information must be selected based on the particular physics principles that are applied to solve the problem.
3. Some of the information needed to solve the problem may be missing; students must first determine the physics principles that will solve the problem, then use their common knowledge of the world to recall specific values (e.g., the boiling temperature of water) or estimate values of relevant quantities (e.g., the length of a table).
4. Reasonable assumptions may need to be made (e.g., assume constant acceleration) to simplify the problem and allow for a meaningful solution.

Because context-rich problems are complex and involve making decisions about physics concepts and principles new to beginning students, they are difficult and frustrating even for the best students. In cooperative groups, however, students share the thinking load and can solve these problems. Because decisions must be made, context-rich problems forced the groups to discuss physics issues while practicing effective problem-solving techniques. The group practice enhanced the students' ability to handle this type of problem individually, as reported in the preceding article.[3]

From observations, questionnaire data, and an examination of written problem solutions, we estimated that about three-fourths of the groups practiced implementing the prescribed strategy to solve context-rich problems. The students had to pool their knowledge of the actual behavior of objects and the physics concepts and principles that describe this behavior to solve these problems. For example, Fig. 2 shows how a well-functioning group solved the traffic ticket problem shown in Table I. This problem is the inclined-plane textbook problem discussed above, rewritten in context-rich form. The students first sketched the situation and discussed what variable was needed to answer the question: "Will you fight the ticket in court?" They decided they should calculate the initial velocity of the car just before the brakes were applied to see if this velocity was above the speed limit of 25 mph. After drawing the kinematics diagram, they then discussed what information they needed to find the initial velocity. They decided they could ignore the information about the child, since "the car stopped before it hit the child." They then spent several minutes drawing free body diagrams of the car and discussing whether they needed to use static friction, kinetic friction, or both. During this discussion, they referred several times to the friction experiments they were doing in the laboratory. Once this issue was resolved and the force diagram agreed upon, the systematically planned a solution, following the planning procedure modeled during lectures.

Context-rich group problems refocused students' discussions on "what physics concepts and principles should be applied to this problem" rather than "what formulas should we use." The students' attitudes toward using the prescribed problem-solving strategy also improved. When groups were interviewed by science educators who were not instructors of this course, students said that they found the strategy "annoying" or "frustrating" to use on simple textbook problems because the strategy required them to write down more than they thought was necessary. (It should be noted, however, that these students were not usually successful at solving these problems using the formulaic strategy they preferred.) These same students

Table I. Examples of context-rich group problems.

Traffic ticket: Introductory physics problem

While visiting a friend in San Francisco, you decide to drive around the city. You turn a corner and find yourself going up a steep hill. Suddenly a small boy runs out on the street chasing a ball. You slam on the brakes and skid to a stop, leaving a skid mark 50 ft long on the street. The boy calmly walks away, but a policeman watching from the sidewalk comes over and gives you a ticket for speeding. You are still shaking from the experience when he points out that the speed limit on this street is 25 mph.

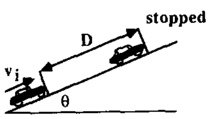
After you recover your wits, you examine the situation more closely. You determine that the street makes an angle of 20° with the horizontal and that the coefficient of static friction between your tires and the street is 0.80. You also find that the coefficient of kinetic friction between your tires and the street is 0.60. Your car's information book tells you that the mass of your car is 1570 kg. You weigh 130 lbs, and a witness tells you that the boy had a weight of about 60 lbs and took 3.0 s to cross the 15-ft wide street. Will *you fight the ticket in court?*

Lifetime of the Sun: Modern physics problem

One day at the office, you and another engineer are discussing the design of a new computer circuit. In the background a radio is on and you both hear a popular song proclaiming, "Baby, I'll be yours until the Sun no longer shines." Your colleague exclaims, "Wow, I wonder how long that would be?" You had astronomy in college and recall the lifetime of the Sun is billions of years. Being the curious sort, you decide to calculate the lifetime of the Sun. You recall the Sun generates energy with the proton–proton cycle and that four protons (hydrogen) are fused into one helium nucleus ($4\text{H} \rightarrow \text{He}$). You also remember that thermonuclear reactions occur only in the hot, dense, core of the Sun, and so only 10% of the available protons are actually used up in the proton–proton cycle. Fortunately a reference book gives you the mass of the Sun, 1.99×10^{30} kg, and the solar luminosity, 3.86×10^{26} J/s. Recalling the age of the Earth to be about 4.5 billion years, you rush into your associate's office to announce the duration of the relationship with "baby."

agreed that the prescribed strategy was very useful for solving the more difficult textbook problems and context-rich group and individual problems given on the tests and final exams.

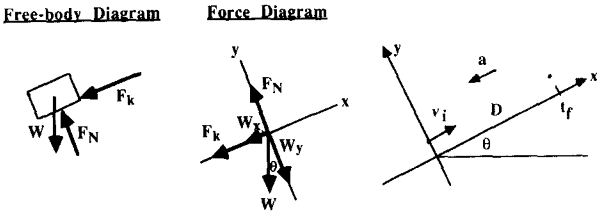
Visualize:



$\theta = 20^o$
$D = 50$ ft
speed limit = 25 mph
$\mu_k = 0.60$
$m_{car} = 1570$ kg
$m_{driver} = 130$ lbs

Question: Is the speed faster or slower than 25 mph?

Physics Description:



W = weight of car and driver
F_N = normal force
F_K = kinetic force of friction
v_i = initial velocity of car
v_f = final velocity of car (0)
t_i = initial time when brakes slammed on (0)
t_f = final time when car stopped

Question: Is v_i less than 25 mph?

General Principles: $\Sigma F_r = ma_r$ $\quad a_r = \frac{\Delta v_r}{\Delta t}$

$W = mg$ $\quad \bar{v}_r = \frac{v_f + v_i}{2}$

$F_k = \mu_k F_N$ $\quad \bar{v}_r = \frac{\Delta r}{\Delta t}$

Plan:

	Unknowns
1. To find v_i $a_x = \frac{v_f - v_i}{t_f - t_i}$	a_x, v_i, t_f
2. To find t_f $\bar{v} = \frac{D}{t_f - t_i}$	$\bar{v}$
3. To find $\bar{v}$ $\bar{v} = \frac{v_f + v_i}{2}$	
4. To find a_x $\Sigma F_x = -F_K - W_x = ma_x$	F_K, W_x
5. To find W_x $\sin\theta = \frac{W_x}{W} = \frac{W_x}{mg}$	
6. To find F_K $F_K = \mu F_N$	F_N
7. To find F_N $\Sigma F_y = F_N - W_y = 0$	W_y
8. To find W_y $\cos\theta = \frac{W_y}{W} = \frac{W_y}{mg}$	

There are 8 equations and 8 unknowns:

Solve #8 for W_y, substitute into #7 to find F_N. Substitute F_N into #6 to find F_K. Solve #5 for W_x, substitute F_K and W_x into #4 and isolate a_x. Equate #2 and #3 and solve for t_f. Substitute t_f and a_x into #1 to find v_i.

Execute: (only last steps shown)

$$v_i = \sqrt{2Dg(\mu\cos\theta + \sin\theta)}$$

$$\text{Units: } \sqrt{(ft)\left(\frac{ft}{sec^2}\right)} = \sqrt{\frac{ft^2}{sec^2}} = \frac{ft}{sec} \quad \text{OK}$$

$$v_i = \sqrt{2 \cdot 50ft \cdot 32\frac{ft}{sec^2} \cdot (0.6 \cdot 0.94 + 0.34)}$$

$$= 53.8 \text{ ft/sec}$$

Change to mph:

$$v_i = \left(\frac{53.8\ \cancel{ft}}{\cancel{sec}}\right)\left(\frac{3600\ \cancel{sec}}{1\ hr}\right)\left(\frac{1\ mile}{5280\ \cancel{ft}}\right)$$

$$= 36.7 \text{ miles/hr}$$

You were speeding -- you better pay the fine!

Fig. 2. The solution of a well-functioning group for the traffic ticket problem shown in Table I.

IV. FORMING AND MAINTAINING WELL-FUNCTIONING COOPERATIVE GROUPS

We investigated several issues related to the structure and maintenance of well-functioning cooperative group. What is the optimal group size for successful physics problem solving? What ability and gender composition of groups results in the best problem-solving performance? How can problems of dominance by one student and conflict avoidance within a group be addressed? How can groups be structured so students are concerned about the performance of all group members as well as their own? The results of the investigations of each of these issues are described in the following sections.

A. What is the "optimal" group size for physics problem solving?

Group sizes between two and six are recommended in other contexts, depending on the nature of the task and the experience of the group members.[13] We experimented with groups of two, three, and four members. An examination of written group problem solutions indicated that three- and four-member groups generated better plans for solving problems and a solution with fewer conceptual mistakes than pairs. For example, to solve the traffic ticket problem shown in Table I, most pairs (80%) included an incorrect "force of the car" or "force of the engine" on their force diagram of the car. Very few groups of three or four members (10%) made this mistake. These results were typical of group performances on other problem solutions examined.

Observations of group interactions suggested several possible causes of the poorer performance of pairs. Groups of two did not seem to have the "critical mass" of conceptual and procedural knowledge for the successful completion of context-rich problems. They tended to go off track or get stuck on a single approach to a problem, which was often incorrect. With larger groups, the contributions of the additional student(s) allowed a 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 by 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. When an impasse was reached, these larger groups often relied on voting. While not an ideal strategy for resolving differences of opinion, voting at least focuses on the issue rather than the personality trait of a particular student.

In groups with four members, one student 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 struggling to convince the three other group members to try an approach, and resorted to solving the problem alone. To quantify these observations, the number of contributions each group member made to the solution of a constant acceleration kinematics problems was counted from the videotapes of a three-member and a 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.

For our students, who have no real experience working in cooperative groups, we concluded that the "optimal" group size for problem solving is three members. That is, a three-member group is large enough for the generation of diverse ideas and approaches, but small enough to be manageable so all students can contribute to the problem solution. The physical arrangement of the students did, however, influence the functioning of the cooperative groups.[14] When three students sat side-by-side, two of the students were often observed engaged in on-task conversations, while the third member was either completely off task (e.g., reading the newspaper) or working in isolation. This did not occur when the students were seated facing each other.

B. What ability and gender composition of groups results in the best problem-solving performance?

In this experiment, students were assigned to groups by ability based on their individual test scores. Students were never allowed to form their own groups. An examination of written problem solutions indicated that instructor-assigned groups of mixed ability (e.g., a high, medium, and low ability student) performed as well as groups consisting of only high-ability students, and better than groups with students of only low or medium ability. For example, on a problem that asked for the energy of light emitted when an electron moves from a larger to a smaller Bohr orbit, 75% of the mixed-ability groups solved this problem correctly, while only 45% of the homogeneous-ability groups solved this problem. This result was typical of other problem solutions examined, and is consistent with other research on the ability composition of cooperative groups.[15]

Observations of group interactions indicated several possible explanations for the better performance of heterogeneous groups. For example, on the Bohr orbit problem homogeneous groups of low or medium ability students had difficulty identifying energy terms consistent with the defined system. They did not appear to have a sufficient reservoir of correct conceptual or procedural knowledge to get very far on context-rich problems. Most of the homogeneous high-ability 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 problems 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 heterogenous (mixed ability) groups, it was usually the low or medium ability student who pointed out that the gravitational potential energy term was not needed. ("But remember from lecture, the electrical potential energy was many times bigger than the gravitational potential energy. Can't we leave out the gravitational term?") Although the higher-ability student typically supplied the leadership by generating the new ideas and approaches to the problem, the low or medium ability student often kept the group on track by pointing out obvious, simple ideas.

In heterogeneous groups, the low or medium ability student also frequently asked for clarification of the physics concept or procedure under discussion. While explaining or elaborating, the higher ability student often recognized a mistake, such as overlooking a contributing variable or making the problem more complicated than necessary. For example, in one group it was the higher-ability student who first thought that both the static and kinetic frictional forces were needed to solve the traffic ticket problem (Table I). This is the same group whose solution is shown in Fig. 2. When the lower-ability student in the group asked for an explanation, the higher-ability 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 necessary.

With a group of three members there is always a gender imbalance, unless a group is all of the same gender. An examination of the written problem solutions indicated that homogeneous gender groups and mixed gender groups of two females and one male performed better than groups with two males and one female. Observations of group interactions indicated that groups composed of two males and one female tended to be dominated by the male students. This was true even when the female member was articulate and the highest-ability student in the group. For example, during their work on a projectile motion problem, a group with a lower-ability male, a medium-ability male, and a higher-ability female had a vigorous discussion concerning the path a projectile would follow. The men insisted on a path following the hypotenuse of a right triangle, while the woman argued for the correct parabolic trajectory. At one point, she threw a pencil horizontally, firmly commenting as it fell to the floor, "There, see how it goes—it does *not* travel in a straight line!" Even so, she could not convince the two men, who politely ignored her arguments.

C. How can problems of dominance by one student and conflict avoidance within a group be addressed?

Even with mixed-ability, three-member groups, two major difficulties prevented some groups from functioning effectively:

1. Dominant personalities: Some groups had a dominant student who railroaded the group into an approach or problem solution. At the other end of the personality spectrum, a timid student would be reticent of participating and often became the silent record-keeper for the group.

2. Conflict avoidance: Even groups that functioned well in other respects had a tendency to resolve issues too quickly by either accepting the first idea proposed or by voting (e.g., "Yes it is! No it isn't! Well, let's vote."). Particularly in the introductory physics class, students initially did not critically examine ideas and suggestions or appropriately argue for or against a particular position. This tendency often resulted in conceptual mistakes in the problem solutions (e.g., frictional forces in the wrong direction).

Two strategies recommended in the cooperative group literature were introduced to address these problems.[7] The first strategy is to define and assign specific roles to each student. The second strategy is for the each group to discuss how well they worked together and what they could do next time to improve their group functioning. Both of these strategies were helpful and are described below.

1. Assigning, defining, and rotating roles

When faced with a difficult task, members of a well-functioning group spontaneously adopt a variety of roles, such as (a) the executive or manager, who designs plans for action and suggests solutions; (b) the skeptic, who questions premises and plans; (c) the educator, who takes on the burden of explanation and summarization; (d) the record keeper, who organizes and keeps track of the results of the discussion; and (e) the conciliator, who resolves conflicts and strives to minimize interpersonal stress. In well-functioning groups, members share these roles and role assumption usually fluctuates over time.[1] The majority of our students, however, were not skilled at performing and sharing these roles. Consequently, instructors assigned specific roles that students were to perform during group problem solving each week.

For groups of three, the roles of Manager, Skeptic, and Checker/Recorder were assigned. The instructor defined each role and gave key phrases a person in that role might say.[16] For example, the Manager keeps the group on task, organizes the task into subtasks, and manages the sequence of steps. Possible phrases for this role are: "We also need to consider..." "We need to move on to the next step." "Let's come back to that if we have time later." The Skeptic plays the role of devil's advocate. This person helps the group avoid quick agreement, asks questions that will lead to understanding, and pushes members to explore all possibilities. This person would say things like: "What else could we say about this?" "Are there other possibilities?" "Before we agree, maybe we should consider..." Finally, the Checker/Recorder checks for consensus among group members, obtains members' consent upon completion of each step, writes the group solution, and turns in the completed problem. Phrases for this include: "Can you explain how we got this." "Let's summarize what we've decided." "Does everyone agree?"

Observations of group interactions indicated that after roles were assigned by the instructor, the number of dominance and conflict avoidance problems decreased. Assigning roles empowered students to take actions they would not spontaneously perform. By rotating roles, students practiced critically examining and discussing a physics problem from different perspectives. 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.

2. Discussing group functioning

The second strategy adopted for addressing problems of dominance and conflict avoidance was to give the groups about 5 min at the end of each activity to discuss how well they worked together.[17] To initiate this discussion, the following instructor-posed questions were used: (1) "What are three ways you worked well together in this problem-solving activity?" or "What did your group like best about this way of solving problems?" (2) "What problems did you have interacting as a group?" (3) "What could you do better next time to interact as a group more effectively?" At the beginning of the course, students wrote individual responses to these questions, then discussed their responses with their group. This was followed by a class discussion of the answers to the third question, so students could consider a wider range of ways groups could function better. Common answers included: 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."). After students became more comfortable working in groups, a discussion of group functioning was needed only occasionally.

Interview data indicated that 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 of 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?" This result is consistent with the research on precollege students.[18]

D. How can groups be structured so students are concerned about the performance of all group members as well as their own?

One of the educational advantages of cooperative-group problem solving is that the roles of Manager, Skeptic, Explainer, and Record Keeper are executed overtly. This verbalization of procedures, doubts, justifications, and explanations helps clarify the thinking of all group members. In addition, students can rehearse and observe others perform these roles, which correspond to the planning and monitoring strategies that they must perform independently and silently on individual problem-solving assignments. These advantages are not experienced when students simply sit in a group but work independently on a problem solution. Research in cooperative group learning indicates that two conditions must be met for students to collaborate on the joint construction of a problem solution, positive interdependence and individual accountability.

Positive interdependence exists when students believe that they are linked with others in a way that one cannot succeed unless the other members succeed. There are many recommended ways of structuring positive interdependence.[19] We experimented first with goal interdependence: students were requested to produce one problem solution and agree on the answer and the solution strategy. An examination of written solutions and observations of group interactions revealed two major difficulties. In many groups, the students did not take the assignment seriously. They talked primarily about their social life, and rarely finished solving the problem. In other groups, students worked independently to solve the problem, usually using a formulaic strategy instead of the prescribed strategy, then compared their solutions. To address these problems, we adopted a second tool for structuring positive interdependence, namely reward interdependence. Each class test was changed to include a group problem which counted as one-fourth of a student's grade for that test. The group test problem was given in the recitation section the day before the individual test problems. Each group turned in one solution, and all members received the same grade for that problem. For all problems, group and individual, students were given points for following the steps of the prescribed strategy as well as for a correct solution.

An examination of written group solutions after these grading practices were adopted indicated a marked improvement in the problem-solving performance of the groups, especially on the group tests. These results were confirmed by our observations of group interactions. The amount of social talk during problem solving decreased, more groups completed the problem, and fewer groups were observed with students working independently. Comments like: "We really have to figure out how to draw vector diagrams before the group test next week!" were common in problem-solving sessions. During these sessions, the general atmosphere was one of "getting the job done." On the group test days, however, the emphasis was on getting the problem *right* rather than just getting it done. Consequently, the most constructive discussions and significant learning appeared to occur during the group tests. These results are consistent with research on precollege students.[20]

Individual accountability exists when students take personal responsibility for mastering the assigned material. In physics classes, individual accountabililty is most commonly accomplished by giving individual tests. After the test, each group member knows how well he or she has mastered the problem-solving assignment. Individual accountability is also important so that group members know (1) which student needs to be helped and encouraged, and (2) that they cannot "hitch-hike" on the work of others.[21] In our experience, these two aspects of individual accountability in cooperative-group problem solving were the most difficult to structure. For example, some students consistently missed the problem-solving sessions, but showed up for the group test (expecting to hitch-hike on the previous work of their partners). We established the rule that if a student were absent from the problem-solving session previous to the test, then that student could not take the group test problem and would receive a grade of zero. The students agreed that this procedure was "fair," and very few students subsequently missed the problem-solving sessions. Two additional strategies were adopted to encourage groups to make sure each member understood the group solution to a problem and how that solution was obtained. While monitoring group work, the instructor questioned the student who seemed to be the least involved in the problem-solving task. During subsequent class discussions, individual students were randomly called on to present their group's answer.[22]

V. APPLYING COOPERATIVE-GROUP PROBLEM SOLVING TO A COMMUNITY COLLEGE SETTING

Given the success of the initial use of the instructional approach in the university setting, we tested the applicability of the method in a community college setting. At Normandale Community College, cooperative groups were used in a sophomore-level modern physics course for physics and pre-engineering majors. This course, which enrolls 10–12 students, has a prerequisite of one year of general physics. Most of the students subsequently transferred to the University of Minnesota electrical engineering program. A major difference from the university introductory physics course was that the cooperative problem-solving groups were led by the course instructor (M.H.). This gave the instructor complete control over the management and structure of the groups as well as the selection and grading of the problems. Some reduction in content (about one chapter of the text) was necessary to allow time for the instructor to model the prescribed problem-solving strategy, as well as time for students to work problems in cooperative groups.

In implementing cooperative-group problem solving in this more advanced context, we investigated similar issues of problem type and group structuring and management procedures. Initially, students solved standard textbook problems, which often dealt with abstract concepts or derivations of physical laws. They were also allowed the use of their textbook and notes. Observations revealed two related difficulties. First, like the introductory students, the modern physics students persisted in their formulaic approach to problem solving. Second, the students spent a great deal of time searching the textbook for appropriate formulas or solutions of example problems similar to the given problem. ("Look on page 89. The problem solved there also uses the photoelectric work potential. Can't we use the same formulas in this problem?")

The first difficulty was solved by designing context-rich problems based on principles having direct technological applications, such as tunneling or binding energy. An example of a context-rich modern physics problem is shown in Table I. The solution to the open-book difficulty was to give each group a sheet with any necessary equations or constants. Observation of group interactions indicated an improvement in group functioning. Fewer groups had students who worked in isolation. More group time was spent discussing which physics principles should be applied to the problems, and how to apply those principles.

The structure and management procedures that produced well-functioning groups in the introductory physics course were also effective in the modern physics course. Groups of three, based on mixed ability levels, were assigned the roles of Manager, Skeptic, and Checker/Recorder. However, there was a different resolution to the problem of the gender composition of the groups. Engineering and physics are still primarily male fields, so the women need to develop their skills in justifying and defending their position. The modern physics class consisted of two women and ten men. The women were good friends and frequently studied together outside of class. However, they were never in a problem-solving group together. At the end of the course, they both expressed their appreciation for the experience of "standing their ground" in male dominated groups.

The Lifetime of the Sun problem shown in Table I provides an example of the effectiveness of this cooperative-group problem solving in the modern physics class. Before the course employed cooperative groups, this problem was given to individual students on a test. Although the students knew they needed to calculate the energy released in the proton–proton cycle, they did not know what to do with the result of that calculation. None of the students solved the problem. A year later when the same problem was given as a group test, all groups arrived at a reasonable solution. This is consistent with the results of the investigation reported in the companion article,[3] in which we found that group problem solutions were significantly better than the solutions of the best problem solvers from each group on matched individual problems.

VI. SUMMARY

We have found cooperative grouping to be an effective means of teaching physics problem solving in two very different kinds of courses: a university introductory physics course and a community college sophomore-level modern physics course. Our current approach to structuring and managing cooperative groups evolved as we gained experience from the experiments recounted in this paper. Students are now assigned to three-member groups on the basis of ability (a higher-ability, medium-ability, and lower-ability student in each group). In the introductory physics course, two women are assigned with one man, or same-gender groups are assigned. In the modern physics course, each woman in the class is assigned to a group with two men. In classrooms with movable chairs, groups are requested to move their three chairs into a circle facing each other. In classrooms with long tables, two students on one side of the table face the third member on the other side of the table. In classrooms with theater-style seating, a student in one row turns around to face his other two partners in the second row.

Once each week students work together on a problem that is more context-rich than standard textbook exercises. They are not allowed to consult textbooks or class notes. The students are assigned the roles of Manager, Checker/Recorder, and Skeptic. These roles are rotated each group session. At the end of a problem-solving session, the instructor occasionally directs the groups in a discussion of the groups' functioning. Approximately three or four times during the 10-week quarter, a problem is treated as a group test and all students in a group receive the same grade on the problem solution. Students are reassigned to a new group after each test. They always have at least two sessions with their new group before the next test.

While it was our intention to implement an effective method for teaching physics problem solving, not necessarily a popular one, student questionnaire data indicate a high satisfaction with cooperative-group problem solving. In the introductory physics course, 72% of the students agree with the statement: "The discussion with my group helped me understand the course material," 21% were neutral, and only 11% disagreed with this statement. Similarly, 68% agreed that "Taking tests as a group helped me to do better on the individual tests," 12% were neutral, and 19% disagreed with the statement. One modern physics student noted, "The group work and problem solving is very helpful in understanding the material. The cooperation of students in each group, by discussing the problem and generating ideas, shows how things are related."

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