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Features

Approaches to Cell Biology Teaching: Cooperative Learning in the Science Classroom—Beyond Students Working in Groups

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In the discipline of biology, researchers increasingly need to collaborate with and access the knowledge and skills of computer scientists, physicists, and cognitive psychologists to push forward lines of inquiry in fields such as informatics, nanotechnology, and neuroscience. Indeed the incredible volume of information in the modern age requires this of most professionals. Yet, most of today's scientists do not begin to learn collaborative skills until they are thrust into the laboratory in graduate school. *Science for All Americans, Project 2061* (American Association for the Advancement of Science, 1989) suggests that the teaching of science and technology should be consistent with the nature of scientific inquiry and that an essential part of scientific inquiry is collaboration.

> The collaborative nature of scientific and technological work should be strongly reinforced by frequent group activity in the classroom. Scientists and engineers work mostly in groups and less often as isolated investigators. Similarly, students should gain experiences sharing responsibility for learning with each other. In the process of coming to understandings, students in a group must frequently inform each other about procedures and meanings, argue over findings, and assess how the task is progressing. In the context of team responsibility, feedback and communication become more realistic and of a character very different from the usual individualistic textbook-homework-recitation approach. (p. 202)

One approach to providing collaborative opportunities for students of biology is *cooperative learning*, a theoretically grounded and well-researched approach in education that can increase students' learning of subject matter and improve their attitudes toward both academics in general and the subject matter specifically (Springer *et al.*, 1999; Johnson *et al.*, 2000). If one knows the definitions of *cooperative* and *learning*, one might assume that cooperative learning is simply the sum of these definitions. Often, cooperative learning is portrayed as simply providing students with a group task or project because of a lack of materials or a low teacher-to-student ratio in the classroom. These scenarios could not be further from the scholarly definition of cooperative learning as recognized in the educational research literature (Johnson *et al.*, 1991, 1993). In fact, much like common words used in biology to connote highly specialized meanings—column, gel, matrix, activity—the specialized educational term *cooperative learning* is much more than the sum of the everyday words that constitute its moniker.

The theoretical foundations of cooperative learning grew out of the work of social psychologist Morton Deutsch who specialized in the study of social interdependence (Deutsch, 1942). Deutsch studied the effects of different group structures—ones that promote cooperation versus competition versus individual achievement—on the processes and outcomes of group efforts in a variety of social and work settings. David Johnson and Roger Johnson (the former of whom was a student of Deutsch's), however, have spent over four decades understanding, developing, and studying effective cooperative learning in the specific context of K–12 schools and the college arena (Cooperative Learning Center [CLC], 2003). As co-founders of the CLC at the University of Minnesota in the 1960s, the Johnsons are renowned not only for their scholarly work in education research but for their commitment to transforming theory into practice and providing resources and strategies for teachers, instructors, and faculty to implement cooperative learning in classrooms in K–12 schools, colleges, and universities.

As an introduction, cooperative learning is often contrasted with competitive learning and individualistic learning, each differing significantly in the structure of student interactions in the classroom (see Table 1). Traditionally, educational settings have taken a competitive approach to learning, and many of those who have succeeded in school and pursued careers in science excel in these environments. Competitive

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Table 1. An Overview of Competitive, Individualistic, and Cooperative Learning Characteristics

Structure of Student–Student Interactions in the Classroom	Common Characteristics
Competitive Learning	• Students work individually. • Students have common learning goals and tasks. • The instructor grades students using norm-referenced methods (e.g., curve-based grading).
Individualistic Learning	• Students work individually. • Students have individualized learning goals and tasks, different from those of other students. • The instructor grades students using criteria-referenced methods (e.g., rubric-based grading).
Cooperative Learning	• Students work in small groups. • Students have shared learning goals and tasks within a group which may be similar or different from other groups. • The instructor grades students both on their work as a group and on their individual work.

learning environments are beneficial in that they prepare students for life experiences such as applying for jobs or competing for grants. In addition, these situations can develop self-reliance and self-confidence in students. However, when students are placed in competitive academic situations, learning may be viewed as a commodity to be competed for, and students can be entrained to view other students as opponents because a students' success is measured against the performance of their peers. In individualistic learning situations, the role of peers is absent. Learning is individualized and sometimes isolated, and success is generally measured against the individual's own learning goals. Individualistic learning can be seen as a rehearsal for what learning may be like for an individual after their formal schooling is complete. In contrast, cooperative learning situations are unique in that students experience learning as a collaborative process. Other students become resources and partners in learning, and the success of a student is, in part, dependent on the involvement of their peers. Given the variety of student learning styles, no one of these approaches can meet the needs of all students all the time, and there is room in any course or classroom for students to engage in each of these types of learning. Indeed, these three approaches can be integrated within a course, even used simultaneously, for example, by engaging cooperative teams in a competitive exercise, not unlike competitive sports do. However, because traditional learning environments have focused almost exclusively on competitive and individualistic approaches, cooperative learning is relatively unfamiliar to most instructors, as well as their students.

WHY BOTHER? THE BENEFITS OF EFFECTIVE COOPERATIVE LEARNING

An often-heard query about cooperative learning is the following: "But, if I succeeded in a predominantly competitive or individualistic learning environment, why should I change my instructional practice to include cooperative learning strategies?" However, the National Science Education Standards emphasize that access to a rigorous science education must be available for all students, not just those who gravitate to the field or consider themselves "science types." As such, all teachers of science—K–12, college, and university—need to reflect on the learning situations they make available to their students and increase the variety of instructional strategies that they use, with the goal of diversifying instruction and reaching all students (NRC, 1996). Studies from the research literature suggest that cooperative learning in its many forms has a variety of positive and measurable outcomes on students at a variety of cognitive levels and in a variety of disciplines. Cooperative learning is one of the best studied pedagogical strategies in the history of education research, with over 1,000 research studies on the topic dating as far back as 1898 (Johnson *et al.*, 2000; CLC, 2003). There are so many studies, in fact, that the most accessible point of entry into the literature are meta-analyses of large numbers of studies. Of primary interest, cooperative learning models have been demonstrated to have a markedly positive impact on student achievement (Johnson & Johnson, 1989; Springer *et al.*, 1999). In a paper available on the CLC website and presented in 2000, Johnson and Johnson conducted a meta-analysis of only that literature that specifically analyzed the impact of cooperative learning on student achievement. In their estimate, students in cooperative learning situations score, on average across many studies, almost two thirds of a standard deviation higher than their peers in competitive or individualistic learning situations (Johnson *et al.*, 2000). More specific to college and university instruction, a meta-analysis of studies of small-group learning in undergraduate science, math, engineering, and technology courses documented clear improvements in academic achievement, attitudes toward learning, and persistence in coursework for these students compared with students who experienced more traditional teaching methods (Springer *et al.*, 1999). The authors of the analysis noted that the "reported effects are relatively large in research on educational innovation," and that the size of the effect across studies would imply that small-group learning would "move a student from the 50th percentile to the 70th on a standardized test," and "reduce attrition from courses and programs by 22%" (Springer *et al.*, 1999, p. 9). In addition to these benefits, cooperative learning has been associated with improved attitudes toward subject matter, increased interest in schooling, expanded student–faculty interaction, improved classroom behavior and climate, and the development of life-long learning skills (CLC, 2003; Johnson, 1989).

THE FIVE ESSENTIAL ELEMENTS OF EFFECTIVE COOPERATIVE LEARNING

Although introducing student collaboration and cooperation into learning situations might appear to be straightforward, in truth, implementation is complex at any cognitive level, from kindergarten to the undergraduate classroom to the scientific laboratory. It is important that Johnson and Johnson emphasized that "putting students into groups to learn is not the same thing as structuring cooperation among students (Johnson *et al*., 1991, p. 18). Based on their research, Johnson and Johnson have proposed five essential elements that are necessary to construct positive, effective cooperative group learning situations: Positive Interdependence, Face-to-Face Promotive Interaction, Individual and Group Accountability, Interpersonal and Small-Group Skills, and Group Processing (Johnson *et al*., 1991, 1993, 1998).

Positive Interdependence

Students must see that their success is dependent on the contributions, inclusion, and success of the other students in the group. Perhaps both the most important and the most challenging of the essential elements, creating positive interdependence requires faculty to craft tasks that actually require the insights and efforts of more than one person. Asking a group of students to cooperatively find the answers to simple questions from a textbook or lecture notes is likely doomed to failure because students would easily be able to accomplish the task individually. However, in the context of biology learning, asking groups of students to propose experiments that would provide evidence that a newly discovered specimen from Mars is a living thing is an example of a task that is both challenging and open-ended, and can be answered in a variety of ways. Positive interdependence can also be promoted by linking the grades given on an assignment not just to an individual performance on the test but to the performance of the other group members. As an example, each group member might be awarded additional points if all members score greater than 90 percent on an exam (Johnson et al., 1991).

Face-to-Face Promotive Interaction

Students must have time and opportunity to exchange ideas orally and discuss the concepts at hand. Most often, this occurs as structured time for discussion during class, often with the discussion scaffolded by a series of questions or controversies posed by the instructor. To ensure student discussion, the teacher may require groups to report to the rest of the class about common confusions and differing opinions, or have individual students turn in summaries of the discussion. In addition, promotive interaction, especially in larger groups, can be achieved through assigning, often randomly, each student in the group a procedural role such as facilitator, reporter, or recorder (for more detail, see *Team Project Roles* section below). This provides every member of the group an entry point for participation and begins to generate individual responsibility within the group.

Individual and Group Accountability

Students must be accountable both for contributing their share of the work as well as for the group reaching its common goal. A common student complaint about group work is that one person does all the work for their group. It is true that this complaint is an indicator that the group work is not structured appropriately to ensure collaboration and is thus not an effective cooperative learning experience. In fact, the aspiration of cooperative learning is to enable students to all benefit from the insights and skills of their colleagues and thus each improve their own learning and skill set. Individual and group accountability is achieved by grading students both on their individual work and on the work of the group, for example, both on an individual laboratory report and on a group-designed and -generated scientific poster presentation.

Interpersonal and Small-Group Skills

Students must not only engage in academic learning but also social learning during cooperative tasks. It is unrealistic to expect all members of a group, at any age or in any context, to come to group tasks fully equipped with the social skills necessary for cooperation. Indeed, explicitly addressing this as part of science education would better prepare scientists, engineers, and health care professionals for the complex social dynamics of our laboratories and clinics. Given that, instructors can aid students in developing these skills by defining and expecting cooperative behaviors. Examples of cooperative skills could include actively listening to all members of the group, actively encouraging all members of the group to verbally participate in discussion, being critical yet supportive of alternative views, maintaining opinions until convincing contrary evidence is provided, and learning how to ask clarifying questions of others.

Group Processing

Students must have the opportunity to discuss how the work of the group is going, what has been successful, and what could be improved. It is unlikely, especially during initial forays, that cooperative group learning will always be optimal for every member of the group. By engaging in group processing, particularly if groups are working together over long periods of time, students are able to improve their skills in working cooperatively, learn to broach difficulties or tensions within the group, and experience the process of resolution and improvement, all skills that are essential in any workplace, from laboratory to faculty meeting. Examples of how group processing can be achieved are through explicit conversation by the group or anonymous written responses that are synthesized and returned to the group by the instructor.

TAKING SMALL STEPS TOWARD COOPERATIVE LEARNING: INFORMAL COOPERATIVE GROUPS OR COLLABORATIVE LEARNING

For those unfamiliar with or new to cooperative learning, designing a unit, course, or laboratory section that fully embodies the five essential elements all at once may seem daunting. It is important to note, however, that the inclusion of all five essential elements is characteristic of extensively structured and developed formal cooperative learning groups, which exist over long periods of time such as a semester, a year, or even multiple years. That said, there are many ways in which instructors can take small steps toward incorporating cooperative learning strategies into their teaching in less formal ways. To sample what cooperative learning might look or feel like in one's own context, consider trying an "informal cooperative learning strategy," also referred to as a "collaborative learning strategy" (Smith & MacGregor, 1992). The common characteristics of these strategies is that they bring students together for collaborative work on a task, but for shorter periods of time and with less structure than formal cooperative learning groups would. Here, we present three possible strategies—peer interaction during lecture, jigsaw groups, and team project roles—although many other informal strategies have been described in the literature (Johnson *et al*., 1991; National Institute for Science Education, 2003), Smith & MacGregor, 1992.

Peer Interaction During Lecture

Instructors who have always used a lecture-based teaching approach often find it the most challenging to take small steps toward cooperative learning. Large, introductory courses that must occur in cavernous lecture halls seem mutually exclusive with cooperative learning. This, however, need not be the case. Informal cooperative learning groups of two to four students can be convened for as little as 5 minutes across the auditorium rows to discuss a challenge question, check for understanding of a concept, or construct a list of concepts that students are finding confusing. These groups can occur before, during, or after a lecture and can provide opportunities both for students to explore their understanding with others and for instructors to listen to student understandings. These groups have no structured continuity and may or may not share the content of their discussions with the instructor orally or in writing.

Jigsaw Groups

Jigsaw groups are an informal cooperative learning group structure that can be used in both laboratory investigations and the discussion of scientific papers or readings. The explicit goal of the jigsaw discussion is for students to share their expertise and to gather information from peers who have completed a different task. For example, students in a developmental biology course may be asked to read articles about body plan patterning during embryonic development. As opposed to having all students read articles on the findings in multiple organisms, each student would be assigned readings highlighting findings in one organism, such as the fruit fly, nematode worm, zebrafish, or mouse. After completing the reading, students would be assigned to jigsaw groups that would bring together four students, each of whom had completed readings on one organism, with the requirement that each student report to the others in an effort to identify common features. This type of jigsaw approach has been successfully used to introduce students to the research literature of biology and provide peer support in understanding the complexities of language in written scientific communications (Fortner, 1999). A similar approach can be taken in laboratory courses in which different groups of students have pursued different investigations on a related topic. In addition, students learning laboratory techniques can hone their expertise on a single methodology in one learning group, and then jigsaw with two or three students who have developed expertise in other techniques, thus promoting mutual teaching and learning among students (Colosi, 1998).

Team Project Roles

Often biology courses have at least one team or group project during the course of a semester, even in the absence of formal cooperative learning. However, these groups tend to have no structure, and the work and productivity of the group may be dictated by the dominant personalities. To facilitate positive interdependence among group members during a team project, instructors can assign, randomly or strategically, specified roles within groups. Assigned roles in cooperative learning are procedural and not roles of intellect or talent; they serve to delegate individual authority to students and engage all students in the work of the group. Scaffolded by these procedural roles, the intellectual work of the group is accomplished cooperatively by all team members. Common procedural roles that can be used in informal, as well as formal, cooperative learning groups include facilitator, recorder, reporter, and time keeper. In addition, instructors may choose to design other procedural roles depending on the age of the students and the nature of the task (Wright, 2002). For examples of common and specialized procedural roles that can be used in cooperative learning groups, see Table 2.

THE SHIFTING ROLE OF THE INSTRUCTOR DURING COOPERATIVE LEARNING

Although much of the emphasis in the cooperative learning literature is placed on shifts in what students are doing and how they are learning, the shifting role of the instructor should not be overlooked. In contrast to more traditional, teacher-centered instruction where an instructor's time is filled with direct instruction and student supervision, cooperative learning delegates authority to students and groups to direct their own learning within the context of the task. In fact, the behavior of the instructor during cooperative learning is critical. If the teacher simply rotates from group to group providing information, mini-lectures, and answers to all questions, there is little incentive for students to rely on one another and wrestle with the issues on their own. In contrast, if the instructor's first response to questions is, "Have you discussed this among your group," and he or she is more selective in intervening, then students must rely on each other. In addition, because much of the work of instruction—designing group tasks, writing scaffolding questions to guide the group, assigning students to groups and roles within groups—occurs before class ever begins, cooperative learning situations offer many faculty unprecedented opportunity for student observation and assessment of student learning. Listening to group conversations can provide insight into key misconceptions or gaps in understanding that may otherwise go undetected. Indeed, collection of evidence in the classroom and an action research approach to one's own practice is very complementary to cooperative learning strategies.

Table 2. Common and Specialized Procedural Roles Used in Cooperative Learning

Common Procedural Roles			
Facilitator	**Recorder**	**Reporter**	**Time Keeper**
• Ensures that everyone understands the instructions or task • Promotes the active participation of all members • Contacts the instructor Monitors pace	• Organizes group report; • Discusses what will be reported; • Summarizes activity for introduction	• Makes sure the group has notes, diagrams, etc. • Checks that everyone has completed individual reports • Sees that reports are turned in	• Monitors time • Advises facilitator • Helps group to complete task within time constraint

Specialized Procedural Roles		
Equipment Manager	**Controversy Moderator**	**Measurement Specialist**
• Gathers materials for activity • Makes sure that the group has and makes use of resources appropriately; • Inventories materials; obtains & returns resources.	• Opens communication • Encourages clarifying questions and non-judgmental responses to opposing views • Identifies and discourages put-downs	• Discusses with group what is to be measured and how; • Makes sure predictions are justified; • Carefully measures for group–time, distance, number, etc.

RESOURCES FOR IMPLEMENTING COOPERATIVE LEARNING APPROACHES

Like all new teaching strategies, cooperative learning requires experimentation and iterative adaptation to one's own context. Even if one is committed to providing students with cooperative learning opportunities, implementing the ideals of the approach brings many challenges and frustrations. Fortunately, there is a host of resources that can aid instructors in troubleshooting difficulties with cooperative learning techniques. For practical suggestions and access to a variety of resources, consider visiting the Cooperative Learning Center website (2003). In addition, the National Institute for Science Education (2003) website has information specifically for college instructors and faculty on approaches to collaborative and cooperative learning. There are also articles that specifically address why some group learning situations fail (Feichtner, 1985), how to convince administrators of the importance of the approach (Cooper, 1995), and a body of work out of Stanford University that addresses the social complexities of group work among heterogeneous populations (Cohen, 1994). These resources are an aid for anyone considering incorporating cooperative learning into their teaching. Like practicing scientists, students can become responsible for their own learning and that of their peers, but only if given the structured opportunities and skills to do so.

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