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The Nuts and Bolts of Cooperative Learning in Engineering

Nikos J. Mourtos

ABSTRACT

A great number of engineering students work alone. But in industry, teamwork is required most of the time. Incorporating Cooperative Learning (CL) into an engineering program gives students an opportunity to practice problem solving and communication skills in a "simulated" professional environment.

The paper briefly discusses the motivation behind using CL in engineering courses. Then, the essential elements to make CL successful in the classroom are examined and examples of how these elements have been incorporated into engineering courses taught by the author are given. Problems that have been encountered along with possible fixes are also mentioned.

WHY COOPERATIVE LEARNING ?

For years, students from Kindergarten to College have associated school with going to a classroom that is set up and operated pretty much like the cabin of an airliner. Each student is usually squeezed between two other students much like the passengers in the coach class of a Boeing 747. Despite this closeness there is very little interaction between students just like there is very little interaction between the passengers of an airliner. All information about the class comes from the front (the teacher, the professor or the teaching assistant) just like all information about the flight (instructions, news, emergency procedures) come from the front (the captain and the flight attendants). Interested, motivated students copy down laboriously whatever is written on the board or placed on the overhead projector while others may be looking out the window, at their watches, or taking a short nap to recover from last night's all-nighter. Again, a striking similarity with the passengers of the 747. A few listening, some reading their books, some looking out the window (and in their case justifiably so), some taking naps. And after landing, the rush to pick up the carry-ons, the race to the exit, trying to beat the crowds, elbowing each other, competing with fellow passengers for the precious little space of the

aisles. Just like the competition in a final exam, trying to beat the crowds by solving more problems than the rest of the class or most of the class anyway, to ensure a precious but very limited commodity called an A grade.

In the real world, however, things are altogether different. In most industry settings, people are not expected to sit in rows and compete with colleagues without interacting with them. It is of no value to an aerospace company which engineer from the aerodynamics group came up with the correct lift coefficient first, or which structural engineer calculated the stresses on the main spar of the wing. Far more important is whether the aerodynamics group reached a consensus regarding the expected performance of the designed wing, and, even more important, whether all the groups (aerodynamics, structures, controls, manufacturing, cost, etc.) feel comfortable enough that the proposed design will fly, will be easy to manufacture and will not cost a bundle of money. Thus, the heart of most jobs is teamwork which involves getting others to cooperate, leading others, helping each other on individual tasks and always aiming at a common goal. Communication, effective coordination, and divisions of labor are a must for any teamwork to be successful.

With this in mind, it is time for engineering classrooms to start reflecting more realistically the realities of industry settings¹. It is time to shift from the competitive and individualized teaching styles to one that emphasizes cooperation^{2,3}. The benefits of using cooperative as opposed to individualized and competitive learning are well documented in the literature⁴. This paper discusses the particulars of how to include cooperative learning in engineering classes. Examples from the author's experience are also given.

ESSENTIAL ELEMENTS OF COOPERATIVE LEARNING

Cooperative learning (CL), as the words proclaim, is learning that takes place while working with someone else. Teamwork is the heart of CL. Simply placing students in groups, however, and telling them to work together will not always give the best results. It is



unrealistic to expect students who until yesterday were pitted against each other in a cruel race to see who is the best, to all of a sudden begin to cooperate and work with each other harmoniously. Some structural elements must be present to act as catalysts and help the students see the benefits of working together instead of competing against each other⁵. These elements are discussed below.

Forming Teams

a. The size of the teams:

The larger the group the larger the range of abilities, expertise, and skills that are available within the group. The number of minds acquiring and processing information and the number of hands available to do the task increases with the size of the group. On the other hand, larger groups require advanced social skills which some students may not have from the beginning, for example providing everyone with a chance to speak, coordinating the actions of group members, reaching consensus, ensuring explanation and elaboration of the material being learned, keeping all members on task, maintaining good working relationships. Lack of these skills will result in a breakdown of the team process.

The way this issue has been dealt with in our "aircraft design" two semester sequence is to limit the size of the team to three members in the first semester while having students work in teams of six to eight in the second semester. Thus, students get an opportunity to practice/develop any missing social skills in a small group environment before they find themselves in a more demanding larger group setting in the second semester. In addition, the detailed design which follows in the second semester requires a greater division of labor and therefore more brains per team. Aircraft design, on the other hand is the kind of class that students have been accustomed to working in groups even before the benefits of cooperative learning were fully recognized. For the typical lecture class where students have not been accustomed to working together, groups of three were found by the author to work the best.

b. The members of the teams:

Teams should be as heterogeneous as possible to provide the best mix of abilities, sexes, and ethnic groups. This enhances elaborate thinking, frequent giving and receiving of explanations and perspective taking in discussing material. Unfortunately, student-selected groups tend to be very homogeneous which makes it necessary for the teacher to step into the process of team-forming. Base groups can be formed in the beginning of the semester to provide each student with a comfortable family-like environment for performing the various tasks (homework, design projects, laboratory

experiments and exams). As the semester progresses team members get to know each other better and feel safer and more comfortable taking risks. However, it is always a good idea to ask students to work with others outside their base group during short class drills to promote a strong positive feeling of collaboration across the entire class.

Positive Interdependence

For CL to work, students must understand that either they swim together or they sink together. Thus, each student has two responsibilities: first, to learn the assigned material, and second, to ensure that all members of their group learn the assigned material. These two must be clearly stated in the beginning of any team work (project, exam, etc..) as a mutual goal. In addition, joint rewards may be added as an incentive.

In aircraft design, the author has struggled with the decision of whether to allow students to work in teams from the very first semester with all the added benefits of CL, or to ask students to work out individual airplane designs in the first semester. The benefit of the second approach is that it allows students to fully master the design process before they join a team in a more demanding project in the second semester.

The solution to this dilemma lies in the fact that holding each student accountable for his/her own design for a term does not necessarily exclude cooperation between individuals. For example, teams of three may again be formed and while each team member is responsible for his/her own design every member is responsible for editing each others reports, making suggestions for improvement, marking any technical errors, and noting strengths. All revised reports are handed in with the signatures of the group members who edited them. Reward-interdependence may also be structured in one or more of the following ways:

- Each individual's reports are graded as usual on a scale from 0 - 100 subtracting 3 points for every English error (spelling, punctuation, grammar, etc.) and 6 points for every technical error found by the professor. But in addition, editors are penalized 1 and 2 points respectively for each type of error in their own scores (negative reward-interdependence).
- If all three individual reports score higher than 90% all scores are rounded up to 100 (positive reward-interdependence).
- If all three individual reports score above 80% editors are given back the points they were penalized for errors they had missed in their teammates reports.

In the second semester of aircraft design where each team is responsible for one design and only one



report is prepared for each assignment, a different kind of problem often arose. The labor was usually divided between team members. For example, in the "performance sizing" assignment, one person would take responsibility for calculating takeoff performance, someone else would do the cruise, a third member would undertake maneuvering, and so on. While there is nothing inherently wrong with the division of labor mentioned above, individual team members were often found totally ignorant of the work done by others in their group even though they were all supposedly working towards the same goal, the successful design of the same airplane. Reports were simply patched together and no effort was made to educate each other about the different issues involved in each part of the design. This problem was addressed in two ways:

- Written, individual quizzes were added throughout the semester to test individual knowledge of basic design issues. This ensured that all students, regardless of their responsibility to work out only certain parts of the design, were aware of the pros and cons of different configurations, knew the criteria for the proper placement of the landing gear, understood the meaning of a longitudinally, statically stable but dynamically unstable airplane, etc.
- During the oral reports, each student was asked questions and was responsible to know how each and every part of the design process had been carried out, not only the parts that he was involved with.

Positive reward interdependence can also be structured in lecture classes. Students are encouraged to study together and coach each other in preparation of a test. All tests have individual and team effort parts⁶. For the individual part of the test:

- Students would receive only 70 percent credit from the number of points they earned. The other 30 percent would come from the average performance of the group members. Or,
- Students would receive 100 percent of their individual score but were given bonus points if all members of the group achieved a preset criterion for excellence (ex. score 90% and above).

Needless to say, if in addition to the individual part of the test there is also a team effort part, this helps to enforce more positive interdependence.

Individual Accountability

All teachers must be familiar with the possibility of creating a new species called the "free rider" every time team work is required of their students. There are several ways, however, to avoid this problem and ensure individual accountability:

- Keep the group size small, as was discussed above, at least in the beginning when the students are not fluent in cooperative skills.
- Give individual tests as described previously.
- Make each member responsible to teach his/her part of the project to the rest of the team. This approach is known as "jigsaw" because each member starts with only one piece of the puzzle and in the end all members are responsible to know how the puzzle is put together.
- Have each student maintain a personal "note book" where he/she records all his/her contributions to the project. All calculations, plots and graphs, sketches and anything which the student did as part of the project may be collected in a binder and presented to the professor upon request any time during the semester. In the second semester of aircraft design this note book is worth 10% of each student's grade.

Individual accountability is extremely important in ensuring that students are actually strengthened by the CL process and do not perceive the group as a crutch without which they cannot function. The test of whether CL was actually structured appropriately and worked well is whether group members are able in the end to perform similar tasks by themselves.

Face-to-Face Promotive Interaction

An element which is easily overlooked in structuring CL among college students is the chemistry that takes place when two or more people are brought close to each other and asked to work together. The various interactions that are present, such as the verbal interchange, the mutual help and support, the encouraging, the explaining, all contribute greatly not only to the group dynamics and increased productivity but also to the growth of each individual. As students exchange ideas and opinions or discuss solutions, they influence each other's thinking and reasoning. At the same time, they provide instant feedback on each other's performance. A byproduct of all this, known as "face-to-face promotive interaction" is that unmotivated team members feel pressured to participate and contribute.

One of the obstacles that needs to be overcome in promoting this face-to-face interaction is the way most college classrooms are structured. Instead of facilitating cooperation most classrooms resemble the cabin of an airliner. This certainly affects student attitude towards working with others. Circular arrangements, where students can easily maintain eye contact are best in this sense.



Professor as Facilitator

So, what is the role of the professor in all this? Of course, he still is the captain of the plane. He still lectures and he still is an authority on the subject taught. But he should not be used as the only source of ideas and solutions. Students should learn to look for the answers themselves first, as a way of preparing for group work. Then problems should be discussed within the groups. The professor should always be available as a consultant but he should be used as such only as a last resort. In lower division classes the professor may have to play also the role of the technical expert. In senior and/or graduate classes on the other hand, this role should diminish as students should learn to rely more on their group and less on their professor. Only if the problem has been discussed extensively within the group and still a resolution does not seem in the horizon should the professor step in and redirect the group's efforts. This applies to individualized learning as well. If students are to learn how to work independently the professor should not immediately pass out answers but he should direct students to the library, to the laboratory, to a book, or whatever is appropriate for the case.

CONCLUSION

In the 1930's issues of individual freedom to compete and fears of collectivist domination set a competitive climate in industry. This climate has since been transferred into the schools, from Kindergarten to College despite extensive research and publications which clearly show the benefits of cooperation in the classroom. The ruthless competition, however, which has dominated industry to this day, seems in many cases to be reversing. At the company level, management has discovered that many engineers, sharp and knowledgeable as they may be, do not know how to work with others, in many cases not even to communicate effectively with others. This has been recognized as a major setback for productivity. In the market place, fierce competition has been replaced with a spirit of cooperation as more and more companies find out that they cannot survive on their own in today's economic realities. The merging of aerospace companies is one example. Lastly, and most important, we have come to witness the age of international cooperation, as the cost of some projects has risen above what companies or even countries can afford.

While the need for better communication skills has been addressed to some degree through technical report writing and oral presentations, the need for cooperation has not been addressed adequately in engineering classrooms. If engineers are expected to work with others in industry, then a spirit of cooperation as well as the necessary social skills must also be

fostered in engineering classrooms. Individualized and competitive learning does not have to be eliminated completely from engineering courses as each offers its own rewards. On the other hand cooperative learning should be the norm and used most of the time in every classroom.

The author can attest that incorporating CL into his teaching, was not at first easy. While it was received enthusiastically by the students CL was not problem free. It takes much time in preparation and thinking, experience gained in the classroom and quite a bit of effort and persistence to ensure true cooperation and learning. On the other hand, the benefits were loud and clear not only in academic performance but more importantly in student attitude towards learning⁶.

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