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Collaborative Learning for Physics Courses at Tecnológico de Monterrey, Mexico City Campus*

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This paper shows different collaborative learning activities implemented in physics courses for junior engineering students at Tecnológico de Monterrey, Mexico City Campus. The application of the Jigsaw Learning Procedure to physics courses is described in detail, and the results obtained show that the average grade of students working collaboratively using the Jigsaw Technique is about 10% higher than that of students working only individually on the same kind of assignments. It was also found that students improve their collaborative competences in later courses of their curriculum.

Keywords: physics education; collaborative learning

1. INTRODUCTION

IN ITS MISSION FOR 2015, the Tecnológico de Monterrey established the acquisition of diverse skills in its graduate students, among which is the ability to work collaboratively. To this end, the Tecnológico de Monterrey trains its professors to encourage in their students the ability to work collaboratively, both in and outside the classroom. The professors at the Physics and Mathematics Department of the Engineering and Architecture School at Mexico City Campus have been implementing various didactic methods, including *Problem Based Learning* (PBL) and Collaborative Learning (CL). These learning approaches are used mainly in the beginning courses of the engineering curricula, particularly in Introductory Physics, which is taken by most new students at the graduate level at the Tecnológico de Monterrey.

2. ELEMENTS OF COLLABORATIVE LEARNING

2.1 Why is collaborative learning important?

Collaborative Learning (CL) within small groups must take advantage of the individual skills and attributes of each group member, and must promote these skills in such a way that the final result reflects not only the mere addition of individual contributions, but also a stronger, more far-reaching effort on the part of the group as a whole [1]. However, the first step to ensure a successful CL activity is to make certain that each group member understands the importance of each individual contribution and accountability, and that each member is ultimately responsible for his or her own learning experience.

2.2 Aspects to consider when forming collaborative groups

A successful CL activity demands a sincere commitment from each group member, as well as from the professor. This includes proactive participation by each group member. Regular meetings must be scheduled, and potential internal conflicts must be put aside. All group members should contribute equally and not simply hang on to the work of others without doing their own part. Likewise, the professor must provide constant and timely feedback to the group.

It is a challenge to successfully integrate a work group, since most students are not accustomed to collaborative work formats. Neri discussed some aspects that must be considered when forming a work group so that CL is truly efficient. Some of these elements include:

- group size,
- individual member characteristics,
- roles within the group.

Depending on the planned task, from two to five group members would be acceptable. Heterogeneity among the group members is also recommended, for example, learning styles [3], selected majors, average grades, sex, or nationality. Each group member must adopt a specific role, in order to equitably distribute the main tasks and to

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improve the overall efficiency of the group. The most common roles are: leader, assistant, critic, and time-keeper.

2.3 Basic elements of work groups

According to Johnson et al. [1], the basic elements for an efficient teamwork include:

a) Individual responsibility. This is an indispensable requirement for successful CL.
b) Positive interdependence. The success of the group as a whole depends on the success of each of its members (One for all and all for one!). This also means that each group member is responsible both for his/her own learning and for the group companions' learning.
c) Encouraging face to face interactions. Sharing ideas and discussing results should be promoted by each group member to enhance individual and collective productivity.
d) Interpersonal abilities in small groups. These include teaching skills, decision making skills, communicating skills, and the ability to solve conflicts.
e) Group processing. Group members must evaluate how the group is working as a whole and identify those elements that should be improved or avoided to accomplish group objectives.

2.4 Professor's role

The role of the professor to promote CL is a real challenge. The professor must carefully design, apply and supervise the activities performed by the group. The professor must also evaluate the group's results so as to guarantee the achievement of the academic and collaborative goals. Occasionally, personal conflicts among group members must also be resolved by the professor.

2.5 Formal and informal groups

Formal groups are those described so far and are meant to work together during the whole semester. Members work together on weekly homework, monthly assignments and mid-term papers. In contrast, informal groups consist only of two to three members who work together within the classroom during a single session, or during part of it. The professor decides the composition of these small groups combining, if possible, students with different average grades and skills. These groups promote camaraderie among the members.

3. COLLABORATIVE LEARNING ACTIVITIES

3.1 Individual and collaborative homework

About ten homework-exercises are assigned by the professor once a week. The first five exercises must be solved individually, and the other five exercises, usually with greater difficulty, must be worked out by the formal team before being turned in for grading.

3.2 Problem Based Learning

Most physics courses at the Tecnológico de Monterrey use Problem Based Learning (PBL) activities. PBLs are worked out by the formal groups and are designed to develop our students' ability to identify and solve common problems. Each group investigates and sets the parameters and variables needed to define and solve a given problem. Defining the problem from an ill-defined scenario is usually a challenge for most students. Emphasis is made on the procedure, methods of investigation and the interpretation of results, rather than on the results themselves (e.g. [4]). In our physics courses, the groups have from two to three weeks to carry out the research, find the solution and present their results. In the meantime, the professor makes sure that each group's research is going in the right direction in order to fulfill the academic content at which the PBL is aimed.

Overall, this CL activity has good acceptance among our students and has given us satisfactory results (see Table 1 below). Examples of the application of PBL activities for physics courses at the Tecnológico de Monterrey, Mexico City Campus have been reported elsewhere [5–7].

3.3 WebQuests

This CL activity is also performed by formal groups and is similar to the PBL. However, in this case, the main problem or impetus is much more well defined. The professor gives specific web-links that lead the students to the information needed to solve the problem.

3.4 Jigsaw Learning Procedure

Here, a guide to the successful application of a Jigsaw Procedure activity in the classroom is adapted from Porres [8]. The professor must carefully administer the time during the activity, which is assumed here to last 90 minutes, although it can be adapted for a 60 minute class.

a) Definition of the activity. The students will collaboratively solve in the classroom three specific physics exercises, previously defined by the professor to meet certain course content.
b) Objective of the activity. The purpose of this activity is to develop our students' ability to solve specific course exercises and to foster their ability to work collaboratively, promoting organization, verbal and non-verbal communication, and positive interdependence. Before the activity, the professor should have explained similar exercises to the whole class, or the students should have worked out similar homework exercises.
c) Satisfaction criteria. The students will know how to solve the three exercises proposed for the session, and will be evaluated at the end of the session with a score from 80 to 100, on a scale from 1 to 100 (see below).
d) Description of the activity.

Table 1. Results of survey on collaborative learning

Did you find it useful to work with a CL activity, either PBL or Jigsaw Procedure?	Yes: 81%. Reasons: • Work is divided and individual duties are reduced. • It allows students to share ideas and knowledge. • Students actually learn more. • It promotes group discussions.
When comparing the Jigsaw Procedure with the PBL, which one was more interesting?	Jigsaw Procedure: 50%. Reasons: • It is a lively activity. • It helps both to point out common errors and to correct them. • It helps to practice what has been taught in the class. • It fosters group work. • There is a more efficient use of time. PBL: 50%. Reasons: • It shows physics applications to real situations. • It promotes research on new topics.
Did you find problems working with the PBL?	Yes: 30%. Reasons: • It demands a lot of work when the group is not well organized. • *Free riders*
Did you find problems working with the Jigsaw Procedure?	No: 86% Yes: 14%. Reasons: • The student's grade depends on the performance of all group members. • To explain and understand better all exercises, more time is needed. • Lack of commitment of some members of the group.
What part of the Jigsaw Procedure better fosters the learning of content?	• 52%. Discussion in similar groups: *A* with *A*, *B* with *B* and *C* with *C*. • 38%. Discussion in small groups: *A* with *B* and *C*.

1) Activity's methodology. The professor explains to the class what the activity is about, including learning objectives, collaborative objectives, satisfaction criteria, and method to evaluate the activity (5 min).
2) Group formation. The professor chooses three members, A, B, C for each group, including if possible, students with different average-grades in order to foster positive interdependence (5 min).
3) To assign and solve exercises individually. The professor presents three selected exercises, A, B, C to be worked out during the session. A printed copy of the exercises can be distributed to each student. Member A will individually work exercise A, and the same for B and C (15 min).
4) To compare the solution of each problem. The professor then gathers all members A on one side of the classroom, and the same for members B and C. All members A will discuss their procedures and results. It is then expected that all A members will know how to correctly solve problem A, and the same for B and C (15 min).
5) To explain all the problems within each group. The small groups are gathered again. Member A will explain problem A to the two others (5 min) and the same for members B and C (15 min total).
6) Group processing. The professor allows 5 to 10 minutes for group members to reflect upon and discuss the activity itself. For example, a) what was the activity about? b) What skills, attitudes and values were developed? c) What are the positive or negative aspects of this CL activity? (15 min).
7) Individual test. The professor will "randomly" choose one member (*A*, *B* or *C*) from each small group and will let the remaining students leave the classroom (they love this part). The professor will apply to each representing member a test in which an exercise, pretty much like those they just discussed, has to be solved (15 min).

e) Evaluation of the activity. The professor must state at the beginning of the activity that the grade obtained in the individual test by the representing member, will also be the grade assigned to all the members of the group (enforcing positive interdependence). The professor must also establish the relative weight that the whole CL activity will have on the student's monthly grade. This CL activity may have a weight similar to a weekly homework.

It is also recommended that the professor think over the activity itself:

1) What was the overall student response to the activity?
2) What can be done to improve the activity's results?
3) Were the learning and collaborative objectives achieved during the activity?

4. DISCUSSION

4.1 Evaluation of CL activities

The application of a CL activity is challenging because the professor should evaluate the achievement of both the academic and collaborative goals. To this end, the professor may use a rubric to evaluate the process followed by the small groups, clearly stating the specific competences and the satisfaction criteria that the students are expected to attain during the activity. With a PBL, the professor must supervise and give timely feedback to the groups, adopting the role of a guide in helping the students to build their own knowledge.

4.2 Impact of the jigsaw procedure on student

Here we present the results of a survey performed in two Introductory Physics courses at the Tecnológico de Monterrey, Mexico City Campus, during the Fall term in 2004. The results from $N = 43$ consulted students are summarized in Table 1 above, including the percentage of students that answered a given question as well as some of their comments.

a) Acceptance, advantages and disadvantages. As it can be seen in Table 1, about 80% of the students enjoyed working with CL activities and think that they were useful, in particular the jigsaw procedure.
b) Problems with CL.
   1) Resistance to collaborative work. Some students show resistance to collaborative work. One reason is that they are not used to it, or to the commitment that it demands; for example, scheduling meetings, distributing roles and activities, and sharing responsibilities. This problem is stronger when the formal groups start working for the first time.
   2) Disagreement with evaluation methods. Some students consider that it is not fair that their grades depend on their fellows' performance. For this reason, the professor must state clearly from the beginning, the benefits and conditions for collaborative work to be successful, including positive interdependence.
   3) "Free riders". Sometimes a group member does not accomplish efficiently and on time his or her part of the job, forcing the rest of the members to cover it. As stated before, each member's performance is decisive in attaining the group's objectives, including of course, their final grades. To identify these free riders, a brief questionnaire may be applied to each member of the small group at the end of the activity (say a PBL), asking them to perform a self- and co-evaluation about the collaborative process itself and the results obtained by the group. This may help the professor to refine his/her perception about the fulfilment of the academic and collaborative goals by each group member.
   4) Wrong distribution of homework assignments. For a given weekly homework assignment, consisting of a set of, say, 10 exercises, the group members tend to just distribute the exercises among themselves, without planning a group discussion to make sure that they understand the related concepts and that they know how to correctly solve all the assigned exercises. This action will sooner or later be apparent in the monthly and final exams. To avoid this problem, the professor may apply in the classroom brief individual quizzes related to the homework assignments, thus identifying the students who did not work their assignments properly.
c) Benefits of the jigsaw procedure and CL on the student's performance. Our Introductory Physics course included, among other, the concepts of dynamics of a particle in circular motion. In the Spring 2004 term, one of the authors covered this content in the traditional way, with the professor explaining the concepts face-to-face, and showing the solution of example exercises in the classroom. However, in the Fall 2004 term, part of the content was covered explaining the concept as before, but the jigsaw procedure was applied as described above. In both semesters' final exam, an exercise with the same difficulty level was included. We found that the average grade for this exercise in the Spring 2004 term (without CL) was 55 (with a standard deviation of 28), while in the Fall 2004 term (with CL) the average grade was 69 (with a standard deviation of 32), both in a scale from 1 to 100. Part of this difference may be due to intrinsic deviations from one group to another. However, from our experience, we believe that the difference is related mostly to the application of CL activities within the classroom. Forcada et al. [9] have also reported small differences in the final grades between traditional vs. blended learning.

5. CONCLUSIONS

From the ideas presented above, it is concluded that the use of CL methods, such as Jigsaw Procedure and PBL in our Physics courses at the Tecnológico de Monterrey, Mexico City Campus, has proven to be a successful tool in that it develops our students' skills in solving problems in this discipline, as well as to increase their ability to communicate and to promote a reflection upon their own learning process.

Another result shared among colleagues of the Engineering and Architecture School of Mexico City Campus is that our students' abilities and skills to work collaboratively improve as they progress in their majors. This is evident in the way they organize group work, as well as in the depth, use of information, and the end products delivered.

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