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Improving Learning in a Database Course using Collaborative Learning Techniques*

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In recent years European universities have been adapting their curricula to the new European Higher Education Area, which implies the use of active learning methodologies. In most database courses, project-based learning is the active methodology that is widely used, but the authors of this paper face context constraints against its use. This paper presents a quantitative and qualitative analysis of the results obtained from the use of collaborative learning in both cross-curricula competences and subject-specific ones in the "Introduction to Databases" course at the Barcelona School of Informatics. Relevantly, this analysis demonstrates the positive impact that this methodology had, allowing us to conclude that it is not only project-based learning that is suitable for these kinds of courses.

Keywords: computing engineering education; database systems; collaborative learning

1. Introduction

Databases are essential to information systems of any organization, taking strategic decisions to improve its business benefits [1]. As a consequence, database related courses play an essential role in the teaching of computer science, information systems and software engineering. One of these courses, "Introduction to Databases" (IDB), is the first database related course in the Bachelor Degree in Computing Engineering (BDCE) at the Barcelona School of Informatics (FIB) of Universitat Politècnica de Catalunya-BarcelonaTech (UPC).

In recent years, European universities, including UPC, are adapting their academic programs to the European Higher Education Area (EHEA). Aside from ensuring more comparable, compatible and coherent higher education systems in Europe, one of the goals of the EHEA is to promote competence-based learning that fosters a change in teaching methodologies, from a lecture-centered approach to a more learner-centered one [2]. Therefore, the active participation of students in the construction of their own knowledge and the achievement of competences, such as interpersonal relationships and teamwork skills, is specifically encouraged.

At UPC, the adaptation to the EHEA was done by following the framework provided by the Tuning project [3]. This project identifies reference points for subject-specific and cross-curricula competences in different areas. Competences represent a dynamic combination of knowledge, understanding, skills and abilities. Subject-specific competences guarantee the acquisition of knowledge in each area, and cross-curricula competences enforce transversal skills and practices that are appropriate for most areas and can be applied to a variety of jobs, situations or tasks [4].

All these circumstances drove FIB to assign the competences stated in the Tuning project to one or more courses of its BDCE. Some additional competences that were considered important for the specific curricula were also assigned to the appropriate courses. The competences assigned to the IDB course are enumerated below:

- The subject-specific competences are: 1) Knowledge of the characteristics, objectives and structure of relational databases. 2) Capacity to correctly define, create, use and manage relational databases. 3) Capacity to evaluate alternative implementations on relational databases regarding some quality criteria. 4) Knowledge of basic aspects of data storage regulation laws, and the security aspects related to the implementation of such regulations. 5) Knowledge of reliability problems related to the use of a relational database and the mechanisms that exist to help avoid them.
- Appropriate attitude towards work is the only cross-curricula competence. This competence can be broken down into several sub-competences: 1) Capacity for teamwork with positive interdependence regarding team-mates. 2) Capacity for learning from other team-mates. 3) Capacity to discern among possible solutions. 4) Active interest in obtaining quality results. 5) Capacity to plan and manage time. 6) Capacity to adapt and manage changes.

The EHEA promotes the use of active methodologies in the teaching–learning process. Active meth-

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odologies refer to an umbrella term that encompasses a range of more learner-centered instructional methodologies such as collaborative and project-based learning [2]. There are many studies that argue that active methodologies are especially effective in engineering education [2, 5–8]. In particular, in computer engineering education, there are examples of the use of active methodologies in different courses such as programming, computer architecture and operating systems [9–11]. In most of the courses, including the database ones [12–18], the preferred active methodology used in the literature is project-based learning.

Project-based learning mainly consists of open-ended student assignments to carry out tasks that lead to the production of a final product that simulate challenges that the students are likely to encounter as professionals. It includes teamwork to be done by students in and out of the classroom throughout the entire course and is especially suited to applying and integrating previously acquired knowledge [2]. In the database area, project-based learning has been applied to empower skills related to a global understanding of database design and other advanced database topics [7, 12–18].

At the FIB, in the IDB course, the use of project-based learning was difficult for several reasons. First, the study plan already has specific subjects to work on semester-long projects. This is true in the case of the database and software engineering project that is covered in a specific course. The FIB recommendation is that non-project courses do not cover semester-long projects. Secondly, the IDB course is the first database subject where the basic concepts of databases are studied. Furthermore, these concepts are required in some other related courses and it is difficult to ensure that they can be properly covered and consolidated in a project. Although project-based learning usually empowers the integration of generic and transversal competences, the acquisition of specific skills and knowledge may suffer with this methodology [18].

For the previous reasons and although experiences in collaborative learning in engineering education are scarce in the literature, since the academic year 2009/10, the active methodology introduced in the IDB course has been collaborative learning instead of project-based learning. Collaborative learning is the instructional use of small groups so that students work together to maximize their own and each other's learning over a well predefined (and relatively short) period of time [19]. It encompasses a range of techniques that allow a focus on the acquisition of specific knowledge and different teamwork abilities in an effective, structured and agile manner, thus facilitating their integration in the classroom.

This paper presents a practical case where collaborative learning has been introduced in the IDB course. After selecting the set of collaborative learning techniques to be used, this work argues why a specific collaborative learning technique is adequate to solve specific types of exercises designed to ensure the acquisition of competences. Finally, this paper presents a quantitative and qualitative analysis of the results obtained from the use of collaborative learning techniques in both the cross-curricula, and the subject-specific competences of the course.

The paper is structured as follows. In Section 2, the IDB course is presented detailing the topics and exercises addressed by the collaborative learning techniques. Examples of these exercises for each technique are explained in Section 3, and the quantitative and qualitative analysis of the results of their use is reported in Section 4. Finally, Section 5 includes some conclusions and ideas for future work.

2. Introduction to databases course

IDB is a compulsory half-year course for the BDCE degree that has six ECTS credits assigned. Sixty percent of the topics recommended by the IEEE/ACM [21] for databases are covered by the course (see Table 1). The remaining topics are studied in two optional courses following IDB.

The classes consist of four face-to-face hours per week over 15 weeks, distributed in 2 hours of theory/exercises and 2 hours of laboratory classes addressing different topics simultaneously. Additionally, students carry out an average of 4 hours of autonomous work. The total number of students enrolled on the course varies by semester (150 students on average), but independently of that number the students are distributed in theory/exercises groups of about 45 students, and laboratory groups of 15 students. The teacher for all the classes of a specific group remains the same throughout the entire course. During the period analyzed in this paper there was no change in staff.

The continuous evaluation of students accounts for 40% of the final grade and an exam corresponds to the remaining 60%. This grade, which reflects the achievement of the subject-specific competences, is complemented by a cross-curricula grade that corresponds to a more qualitative evaluation of the cross-curricula sub-competences achievement. The grading system of our country grades from 0 to 10, 5 being the lowest passing grade.

Theory classes are lectures where the teacher presents a topic or where he/she helps to resolve doubts. In Table 1, theory classes are denoted by a "T", and they have an "*" to denote a topic autonomously studied by students with didactic material provided by the teacher.

Table 1. Topics and types of classes in the IDB course

Topics				
Theory and exercises classes			**Laboratory classes**	
Introduction to databases	T	–	–	
The relational model	T	–	SQL and relational algebra	L(*)
Relational database components	T(*)	E1	Stored procedures and triggers	L(*)
From UML to relational design	T	E2	Database programming with JDBC	L(*)
Transaction management	T(*)	E3		
Secondary storage management and index structures	T	E4	–	

In *Laboratory classes*, students solve exercises using a computer to practice the use of relational databases with the support of a teacher. Currently, the relational database management system PostgreSQL is used jointly with the Learn-SQL (Learning Environment for Automatic Rating Notions of SQL) system [22], a Moodle system [23] extended by a new type of questionnaire that automatically corrects database exercises and gives feedback to students. Table 1 illustrates the topics practiced in the laboratory classes, denoted by an "L". As before, the "*" denotes topics autonomously studied by students.

Exercise classes deal with the topics of the theory classes (see Table 1), where additional practice is considered necessary, by means of exercises in the Application level of Bloom's Taxonomy [24]. In some of the exercise classes, the teams of students apply collaborative learning techniques to practice and evaluate their understanding of a topic. These are the techniques whose results are analyzed in Section 4 of this paper. During the exercise classes there is a teacher or mentor who guides the implementation of the learning technique. No computers are used in these classes.

The teams remain the same for the whole course to increase positive interdependency. In order to select the number of students in each team and their composition, the number of students and homogeneity in classes was considered. Specifically, as stated above, exercise classes have 45 students, and the only relevant heterogeneities identified are the existence of repeating students and students who work with databases in their job. In summary, the teams are composed of three students, since this means there are 15 teams per class. Having a lower number of students per team was rejected as it implied too many teams per class, and having more students per team was rejected since, as stated in [25], it would increase the chance that some students would not work enough. Furthermore, the composition of teams was decided to be randomly generated, establishing constraints to avoid having more than one repeating or experienced student in the same team.

Some of the aspects related to exercises and exercises classes that are important to note are as follows. Students are allowed to look at didactic materials in the exercise classes, no matter which collaborative learning technique is applied. Exercises are scheduled the week after the explanations of the assessed topics have been completed in theory classes. Exercise statements change every semester, although they are similar in their content and difficulty. All the teams enrolled in the same exercise class group receive the same statements, but changes in these statements are introduced when the exercise class groups' schedule does not coincide. Teachers evaluate the solutions provided by the students and they add as many comments as necessary in order to provide enough feedback regarding subject-specific and cross-curricula competences. This feedback is delivered to the students in the next theory/exercise class.

3. Use of collaborative learning techniques in exercises

In order to select the collaborative learning techniques to be used in the IDB course exercises, specific literature was studied [15–17, 26–28]. Four techniques were initially selected and adapted, and the use of the technique in exercise classes began in the autumn semester of the academic year 2009/10 (0910AS). In previous semesters, students solved the exercises individually.

Table 2 shows the alignment of exercises (from E1 to E4) and collaborative learning techniques by the semesters in which they were applied. The reader can observe that in the semester 0910AS, three of the four techniques were used in the last three exercises. They were well received by students and the teachers recognized their potential value as a means to develop the cross-curricula competence assigned to IDB. Thus, in the spring semester of the same academic year (0910SS) the four techniques were tested.

The definitive alignment between collaborative learning techniques and exercises was finally established in the semesters 1011AS and 1011SS, and it has remained consistent since then. Students receive information about the scheduling of exercises and

Table 2. Collaborative learning techniques used in the IDB course

Collaborative learning techniques used		Exercises			
		E1	E2	E3	E4
Semesters	0910AS	–	Write-Pair-Share	Structured-Problem-Solving I	Send-A-Problem
	0910SS	Structured-Problem-Solving I	Send-A-Problem	Write-Pair-Share	Structured-Problem-Solving II
	1011AS 1011SS	Structured-Problem-Solving I	Structured-Problem-Solving II	Write-Pair-Share	Send-A-Problem

the proposed collaborative learning techniques at the beginning of each semester, although they do not know in advance which specific collaborative learning technique will be applied in each exercise.

Table 3 details which sub-competences in the cross-curricula competence assigned to IDB are practiced in each collaborative learning technique. As can be observed, all the techniques practice three of the six sub-competences. The way that two of them are practiced may be explained in general for all the techniques and exercises, since in all techniques there is a limited number of resources and time for doing the exercises (*Capacity to plan and manage time* is, thus, practiced) and in all the techniques the students are *Actively interested in obtaining a quality solution* in order to have a better grade for the exercise. The other competences (*Capacity for learning from other team-mates* included) are practiced depending on the specific collaborative learning technique used and, thus, explained in each specific section later.

In this section, the rationale behind the final alignment, practical examples of concrete exercises performed and the explanation of how specific sub-competences are practiced is discussed.

3.1 Example of exercise E1: Relational database components

Exercise E1 is devoted to assessing the students' degree of understanding with respect to relational data and control components. Figure 1 presents an example of Exercise E1 related to assertions and views. Although assertions are not implemented in commercial database management systems, they facilitate the comprehension of triggers studied in laboratory classes. Therefore, from a pedagogical perspective, Exercise E1 also aims to make evident that content explained in theory/exercises classes is close to that provided in laboratory classes. The collaborative learning technique applied in E1 is an adaptation of the Structured-Problem-Solving technique [26]. The procedure works following the three steps below:

1. Each team receives a set of exercises (such as those included in Fig. 1) that are based on the same database schema.
2. Students solve the exercises jointly with their team-mates. The teacher can answer questions during this part of the activity. The assigned time for this step is 40 minutes.
3. Each student receives a set of exercises similar to the previous one that, now, has to be solved individually. In this step, no support from the teacher is provided. An example of these exercises is also shown in Fig. 1. The assigned time for this step is 40 minutes.

In this collaborative learning technique the grade obtained by each student is the best grade achieved by the individual team members, provided that all their grades are above a specific minimum level. Otherwise, each student receives the grade obtained in the exercise that he/she has delivered.

The Structured-Problem-Solving technique helps

Table 3. Cross-curricula competences practiced in each collaborative learning technique

Cross-curricula competences practiced in collaborative learning techniques		Collaborative learning techniques			
		Structured-Problem-Solving I	Structured-Problem-Solving II	Write-Pair-Share	Send-A-Problem
Appropriate attitude towards work sub-competences	Capacity for teamwork enforcing positive interdependence regarding team-mates	Yes	Yes		Yes
	Capacity for learning from other team-mates	Yes	Yes	Yes	Yes
	Capacity to discern among possible solutions			Yes	Yes
	Active interest in obtaining quality results	Yes	Yes	Yes	Yes
	Capacity to plan and manage time	Yes	Yes	Yes	Yes
	Capacity to adapt and manage changes				Yes

Topic: Relational Database Components (E1)

The schema of a database is:

PROFESSORS(id, name, telephone, salary)

OFFICES (building, office-number, area)

ASSIGNMENTS(prof-id, building, office-number, assignment-date, un-assignment-date)

{prof-id} is a foreign key that references PROFESSORS

{building, office-number} is a foreign key that references OFFICES

un-assignment-date has NULL value in valid assignments

Step 1-2

Define in standard SQL an assertion to guarantee that there is not any professor in the database that has two or more valid assignments.

Define a view that allows to query the identifier, name and telephone number of the professors of the database that have three or more assignments to different offices of the same building.

Step 3

Define in standard SQL an assertion to guarantee that there is not any office in the database that has two or more valid assignments of the same professor.

Define a view that allows to query the building and number of the offices of the database whose area is lower than the average office area of the same building.

Fig. 1. Example of Exercise E1.

students to identify, analyze and solve exercises in an organized manner. Step 3, which does not exist in the original collaborative learning technique, has been added for several reasons: 1) Step 3 allows the assessment of the degree of knowledge achieved by each student. 2) *Capacity for learning from team-mates* may also be assessed as a result of step 2. 3) *Capacity for teamwork, enforcing positive interdependence regarding team-mates* is also promoted, since the grades of individual student solutions can affect their team-mates positively or negatively. Therefore students are interested in guaranteeing a homogeneous level of knowledge within the team and they try to avoid, amongst other things, lazy attitudes.

The key to the success of this collaborative learning technique is that the exercises performed in steps 2 and 3 have a similar level of difficulty and they require a similar strategy to be solved. As a consequence, students respond very well to this technique and once they have finished and delivered their exercise, quickly share comments and solutions with their team-mates. For this reason this collaborative learning technique was finally selected as the first one to be applied in a semester.

3.2 Example of exercise E2: From UML to relational design

Exercise E2 aims to assess the students' knowledge level in relational database design. Specifically, students are asked about the process of converting a UML class diagram into a relational database design. Again, as in the case of Exercise E1, the applied collaborative learning technique is an adaptation of the Structured-Problem-Solving technique [26]. In this case, the procedure is:

1. Each team receives an exercise which includes a UML class diagram (see Fig. 2).
2. Students solve the exercise jointly with their team-mates. The teacher resolves doubts if necessary during this part of the activity. The assigned time for this step is 40 minutes.
3. A student is randomly chosen as the representative of each team. The selected students must solve an exercise similar to the one solved in step 2. The assigned time is 40 minutes and no support from the teacher is provided.

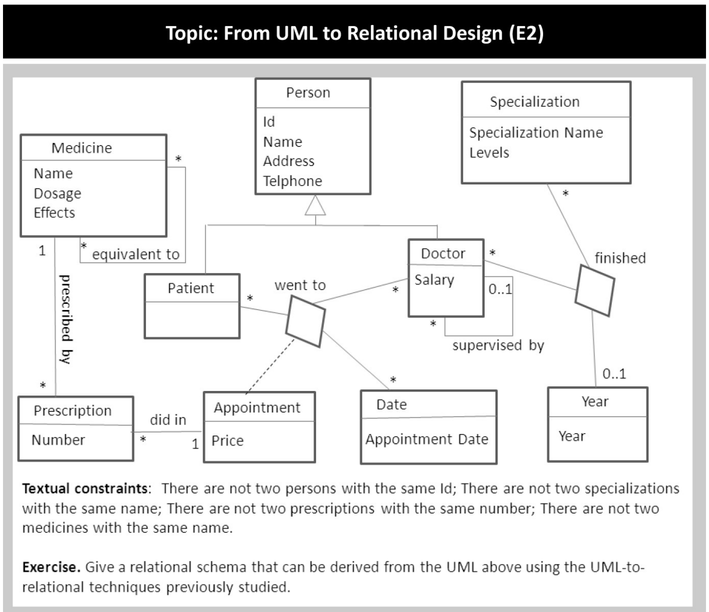


Fig. 2. Example of Exercise E2. Steps 1–2.

The grade of each student in a team is the grade of the solution delivered by the randomly selected student.

Capacity for learning from team-mates is practiced during steps 1 and 2 as far as they are similar to the ones in Exercise E1. Step 3 differs considerably from the adaptation made in E1, since just one student from the team is chosen to solve the second exercise and this student assumes the responsibility for the grade of their team-mates. *Capacity of teamwork, enforcing the positive interdependence regarding team-mates* is, therefore, promoted. When the student has been chosen, the team-mates attempt to give him/her accurate advice. Although the selected student could feel overwhelmed, teachers consider that this risk can be taken, given that the knowledge assessed in Exercise E2 has a procedural nature and a systematic approach to obtain a relational database design from UML diagrams has been deeply discussed in the theory classes. This is the reason behind the decision to apply this collaborative learning technique in Exercise E2.

3.3 Example of Exercise E3: Transaction management

Exercise E3 has as objective the assessment of the students' level of knowledge of database transaction management. The applied collaborative learning technique is based on the Write-Pair-Share technique, which in turn is based on the Think-Pair-Share technique [26]. The procedure works as follows:

1. Each student receives a set of exercises (such as those included in Fig. 3), and has to solve them individually. He/She is also asked to deliver his/her solution proposal. The assigned time for this step is 30 minutes. The teacher resolves doubts (if necessary) during this part of the activity.
2. The students join their team-mates and share and discuss their solutions. The assigned time for this step is 30 minutes. The teacher addresses doubts (if required) during this part of the activity.
3. Each team must prepare and deliver a joint solution for the same set of exercises solved in step 1 and discussed during step 2. The assigned time for this step is 20 minutes and no support from the teacher is provided.

Although the solutions provided during steps 1 and 3 are evaluated by the teacher, the final grade assigned to each student corresponds to the grade granted to the agreed solution delivered by the team in step 3.

With regard to the cross-curricula competences, this collaborative learning technique promotes them this way: 1) *Capacity to discern among possible solutions*, choosing the most appropriate among the individual solutions, in step 3. 2) *Capacity for learning from other team-mates* during step 3 given that the same set of exercises is solved. In fact, students are gratefully surprised (and they perceive it as an extra motivation) when they know that they can meet with their team-mates and work together on the same set of exercises. In addition, there is a further relevant pedagogical reason that has guided the design of this collaborative learning technique. This reason (based on teachers' experience) is related to the topics covered in Exercise E3 that are usually hard to understand (transaction isolation problems and related theory). The possibility of thinking in the same exercises, first on their own, and later in teams, helps in the comprehension of the topic.

Topic: Transaction Management (E3)

The schema of table employees is:
Employees(id, name, salary, city, department-number)
Suppose that transaction T below is executed in a system where the rest of transactions are read-only.

T
Q1: SELECT * FROM Employees WHERE name = 'Anna';
Q2: UPDATE Employees SET city= 'Barcelona' WHERE name = 'Anna';
COMMIT;

1- Explain which is the minimum isolation level of transaction T to avoid any isolation phenomena in its execution.
2- Assume that transaction T is executed SERIALIZABLE isolation level. Explain which isolation phenomena can be produced in the rest of transactions, and the minimum isolation level in which they have to be executed to avoid them.
3- Assume that transaction T finishes with Rollback instead of Commit and that it is executed in SERIALIZABLE isolation level. Explain if there is some other isolation phenomena that can be produced in the rest of transactions, and the minimum isolation level they have to be executed in to avoid them.

Fig. 3. Example of Exercise E3. Steps 1–2–3.

It is important to note that this collaborative learning technique was the first technique applied during the 0910AS (see Table 2), but teachers concluded that this technique was not appropriate to be the first to be used in the course. The main reason is that in this technique the grade obtained by the team also becomes the grade of each student. Therefore, the work performed individually in the first step has no direct impact on the grade. Teachers realized that some students assumed that the rest of exercises would have a similar dynamic and they did not study the topic enough to be positively assessed in the exercise class, trusting in the work of other team-mates.

3.4 Example of Exercise E4: Secondary storage management and index structures.

Exercise E4 is devoted to assessing the students' levels of understanding of issues related to physical database design. The applied collaborative learning technique is a variation of the Send-A-Problem technique [26]. The procedure is:

1. The teacher prepares three exercises that deal with different (though related) topics, such as those presented in Fig. 4. Each member of the team individually solves one of these exercises. For example *student A*, playing the role of *author*, solves Exercise 1. The assigned time is 40 minutes and no support is provided by the teacher.
2. Afterwards, each member of the team individually checks and corrects (if necessary) the solutions of another team-mate. For example *student B*, playing the role of *referee B*, checks and corrects the solution provided by *author A*. The assigned time for this step is 25 minutes and no support is provided by the teacher.
3. Finally, each member of the team takes the solution and the correction done by the other two and delivers a final solution to the teacher (based on his/her criteria, he/she can add new corrections). For example *student C*, playing the role of *referee C*, checks and corrects all work done by *author A* and *referee B*. The assigned time for this step is 15 minutes and no support is provided by the teacher.

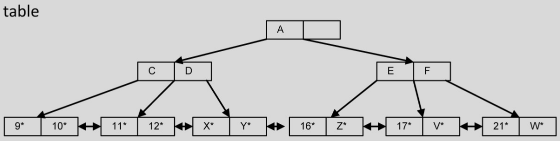
Only the final solution provided by the student playing the role of second referee in each exercise is assessed and all the members of the team receive the same grade, which is computed as the average of the grades assigned to each proposed exercise.

Topic: Secondary Storage Management and Index Structures (E4)

Exercise 1
Table products (with schema: Prod (pid, category, price,...)) has 600000 products and these products are stored in pages that have around 10 records per page.
A B+ tree has been created on the attribute pid and it has an order d=146.
Determine the maximum number of index nodes. Justify your answer.

Exercise 2
Table products (with schema: Prod (pid, category, price,...)) has 600000 products and these products are stored in pages that have around 10 records per page. The attribute pid is the primary key and is distributed uniformly between 1 and 600000.
A non-clustered B+ tree has been created on the attribute pid. Its order is d=146, and the fill factor is 75%.
Determine how many pages (of index and data) need to be accessed to solve the following query. Justify your answer.
SELECT count(distinct category) FROM products WHERE pid >=580000

Exercise 3
Given the following B+ tree (with order d=1) created on the primary key of a table



Explain briefly which are the possible values for X, Y, Z, V and W.
Explain briefly which are the possible values for C and D.
Explain briefly which are the possible values for E and F.
Explain briefly which are the possible values for A.

Fig. 4. Example of Exercise E4. Steps 1–2–3.

With regard to the cross-curricula competence, this collaborative learning technique specifically helps to develop: 1) *Capacity to adapt and manage changes of role in the team*, since in each step each student plays a different role. 2) *Capacity to discern among possible solutions*, since in step 3 each student must select and deliver one of the solutions for an exercise. 3) *Capacity of teamwork, enforcing positive interdependence regarding team-mates* is also present in the last step, since each student is responsible for delivering the best solution, affecting the grade of all the members of the team. 4) *Capacity for learning from team-mates* is improved one more time either in steps 2 and 3. Each student has to understand the solutions made by their team-mates and think about the validity or not on these solutions.

It is important to note that this collaborative learning technique is the most complex one from an organizational perspective. However, from a pedagogical point of view, it allows students to make the connections between related concepts at different levels of abstraction in an agile and dynamic manner. This can be seen in Fig. 4: while Exercise 2 illustrates how indexes can help to solve queries efficiently, Exercise 3 deals with B+ tree properties and Exercise 2 with access methods and costs. For all these reasons, this technique is used in the last exercise of the semester, when students have enough experience in the use of collaborative learning techniques and all the course topics have been explained.

4. Analysis and discussion

In Fig. 5, the average grades in six semesters of the IDB course are shown. Specifically, they correspond to the two previous semesters and the introduction of collaborative learning techniques (0809AS, 0809SS) and the first four semesters after that introduction (from 0910AS to 1011SS).

During the 0910AS semester only, three of the four techniques were met with in the last three exercises (see Table 2). The grades obtained by students during that semester were higher than those obtained in the previous ones, when non-collaborative learning techniques were used. The only exception was on the results of Exercise E3 when the Structured-Problem-Solving I was applied. The reason seems to be that in this collaborative learning technique the exercises solved in steps 1 and 3 must be similar (see explanation in Section 3.2) but in that semester this rule was not fulfilled. Despite this deviation, the grades obtained in Exercise E3 during the 0910AS semester were higher than those obtained specifically in the

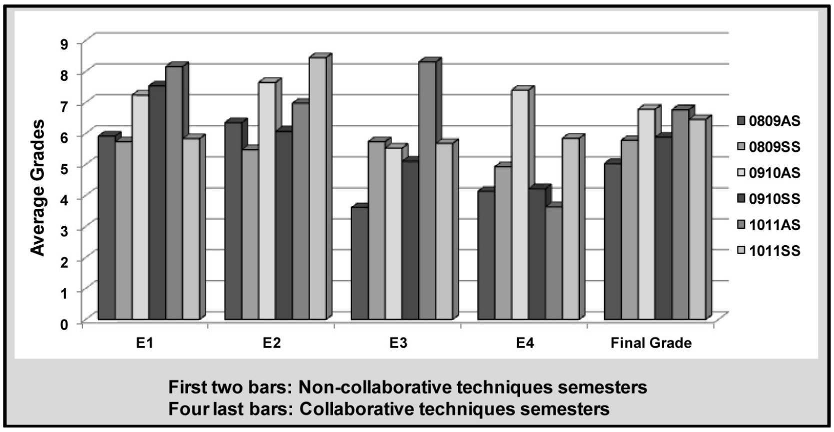


Fig. 5. Average grades in exercises of the analyzed semesters.

0809AS semester where collaborative learning techniques were not used.

In 0910SS all the techniques described in Section 3 were applied, but they were not definitively aligned with the exercises. The grades obtained were not very promising, but it was considered that this was due to the unsuitable selection of the collaborative learning techniques used for each exercise.

However, once the alignment of collaborative learning techniques and exercises changed for the last time, the results obtained by the students improved. The bar chart in Fig. 5 shows that the average grades obtained by students in the 1011AS and 1011SS were higher than those in the 0809 semesters. The only exception was in the grades of Exercise E4, due to the complexity of the Send-A-Problem technique implementation. This technique requires the three members of the team to have a good knowledge of the topics that the exercise is practicing. In the 1011SS semester, the students experienced a peak in their workload coming from other courses in which they were enrolled at the same time as the topic related to Exercise E4 was introduced. Because of this, they were not able to acquire enough knowledge prior to the exercise. To avoid this problem, in subsequent semesters the importance of being very well prepared was stressed before E4. In any case, the final grades were also high.

The intuitive conclusion is that collaborative learning techniques do indeed improve learning. Nevertheless, a statistical study to analyze the correlation between the final grades and the use of collaborative learning techniques was done to validate this hypothesis.

The statistical study consisted on a univariate analysis that provided the description of the grades' features, a bivariate analysis that correlated the grades with semesters and a linear regression that showed the estimate of the average increment per semester in student grades. Finally, a mean comparison between grades of the two types of academic program (traditional and collaborative learning) was performed with the use of Student's t-test for independent samples. In this section, the results of the three analyses and the trend graph of the mean per semester with the corresponding confidence intervals are presented. A qualitative study of the students' opinion is also reported.

4.1 Univariate analysis

Table 4 shows some descriptive statistics for the grades corresponding to the six semesters analyzed. It is important to note that the grades for the first four semesters were rounded according to the students' record book, while in the last two semesters no rounding was applied to the grades. According to this analysis, 25% of the grades were lower than 5 (1st quartile), 25% between 5 and 7 (median), 25% between 7 and 8 (3rd quartile) and the rest greater than 8. The standard deviation was quite high, which indicates that the grades' values were far from the mean (6.22).

4.2 Bivariate analysis

Figure 6 shows the distribution of grades for each semester and academic program. Data is organized according to the type of academic program (traditional or collaborative learning) and the semester of

Table 4. Descriptive statistics for grades corresponding to the analyzed semesters

Analyzed period	Number of grades	Minimum grade	1st quartile	Median	Mean	3rd quartile	Maximum grade	Standard deviation
From 0809AS to 1011SS	928	0.00	5.00	7.00	6.22	8.00	10.00	2.61

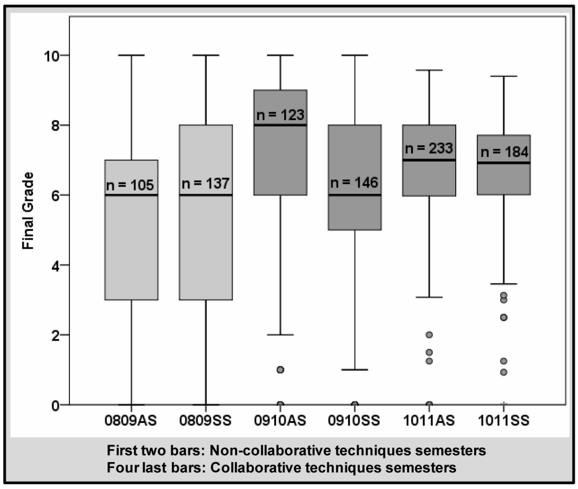


Fig. 6. Grades distribution for semester and academic program.

use. Each bar represents the data set of one semester. The number inside each bar is the total number of students enrolled in the corresponding semester. The line inside each bar represents the median, while the dots represent the outliers (grades further than 1.5 IQR -Interquartile Range- from the box), also included in the analyses. The analysis of these grades shows that in the last two semesters the grades became quite uniform compared with the grades that correspond to the 0809 semesters. It is particularly interesting to emphasize that the lower grades of the semesters in which collaborative learning techniques were used show improvement compared with the lower grades of the semesters in which non-collaborative learning techniques were used.

Table 5 describes in more detail the grades of the period analyzed. The median value indicates that the central value of the dataset was higher in the latter four semesters, when collaborative learning techniques were used. However, the standard deviation decreased in the latter three semesters, indicating that the grades values were not far from the mean. In fact, at least 50% of the grades were between 5 and 8 in the last three semesters. On the other hand, in the 0910AS, 50% of the grades were between 6 and 9 ($SD = 3.17$). The belief is that this exception occurred because in this semester non-collaborative learning techniques and collaborative learning techniques were combined and the introduction of a new methodology positively predisposed the students.

4.3 Grades increment estimation using the linear regression

Figure 7 shows the estimated regression line and the average grades for the six analyzed semesters. The dots represent the grades (a random perturbation in space has been applied in order to visualize the number of dots that correspond to the same grade). The diagonal line is the adjusted linear regression and the straight lines represent the average grade for each semester.

The linear regression analysis indicates that the grades level increases. The average increase of the grades estimated by semester was 0.25, with 95% confidence interval (CI95%) from 0.15 to 0.35. The coefficient of determination (R^2) was 0.025; slightly lower than that obtained by considering two stages with constant grades.

4.4 Trend graph of the mean

Figure 8 displays the average grade with its CI95% by semester. In a scale of 0 to 10, the average grade with the new academic program was 1.04 higher, CI95% from 0.66 to 1.42. This means that, at a minimum, with a confidence level of 95%, using collaborative learning techniques, a 0.66 increase in the mean of the grades can be expected.

4.5 Mean comparison corrected by the design effect

The findings presented should be replicated in samples with a longer follow-up in order to consider a possible dependence of the groups of students coming from the same semester (cluster effect), for example, due to "contamination" or a course/teacher effect.

The observational design has the challenge that these groups could have been different at baseline, that is, students from the latter semesters could have been more able students. However, this situation can be discarded because during the same six semesters the indicator of students' performance for the whole BDCE of the FIB scarcely changed [29].

Table 5. Descriptive statistics of grades by semester

Semester	Number of grades	Minimum grade	1st quartile	Median	Mean	3rd quartile	Maximum grade	Standard deviation
0809AS	105	0	3.00	6.00	5.03	7.00	10.00	2.82
0809SS	137	0	3.00	6.00	5.78	8.00	10.00	3.08
0910AS	123	0	6.00	8.00	6.78	9.00	10.00	3.17
0910SS	146	0	5.00	6.00	5.88	8.00	10.00	2.81
1011AS	233	0	5.98	7.00	6.77	8.00	9.58	1.86
1011SS	184	0	6.01	6.92	6.45	7.71	9.40	2.03

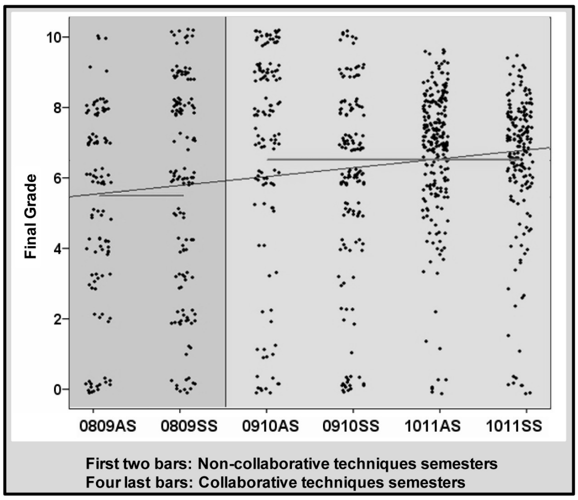


Fig. 7. Linear regression.

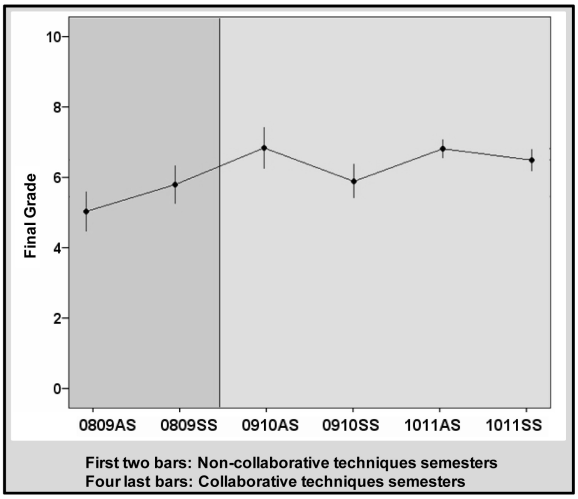


Fig. 8. Average grade with its CI95% by semester.

4.6 Qualitative analysis

During the 0910SS, 1011AS and 1011SS semesters, a short poll was taken on the students' degree of satisfaction with regard to the collaborative learning techniques used. The results of this poll are shown in Table 6.

The results show that students were reasonably satisfied with the collaborative learning techniques. Specifically, they believed that these techniques helped them not only to improve their grades but also to learn more about the course topics. Moreover, they indicated their preference for making exercises using these techniques.

5. Conclusions

This paper has presented the collaborative learning techniques selected and adapted within the IDB course at the FIB. The authors' motivation was the introduction of active learning methodologies to improve learning and to encourage the acquisition of competences. Experiences in collaborative learning in engineering education are scarce in the literature but, as explained in the introduction of this paper, the course's context (EHEA, UPC, FIB) prevents a reliance on project-based learning, the most used active methodology in the area. Anyway, as has been explained and proved in Section 4, it can be claimed that collaborative learning is also effective in dealing with the course. The proposal could be complemented with project-based learning in laboratory sessions to reinforce cross-curricula competences (especially *Capacity to adapt and manage changes, which* is covered by the Send-A-Problem collaborative learning technique used only in Exercise E4) if the context allowed one to do so.

The statistical study has shown that using collaborative learning techniques the average grades were 1.04 higher (CI95% from 0.66 to 1.42) compared with the grades of courses where collaborative learning techniques were not applied. Moreover, a poll conducted at the end of some semesters showed that students are not reluctant to use these techniques. In fact, they believed that they helped them to learn more about the course topics.

The proposal presented may be useful to other courses, modifying it according to different needs and conditions affecting the rationale behind the selection and adaptation of techniques that has been provided in Section 3.

Table 6. 0910SS, 1011AS and 1011SS poll results.

Semesters	Questions	Answers	1	2	3	4	5	Avg.	St. dev.
0910SS	The CoLT have helped me to learn more.	72	4	8	20	26	14	3.6	1.0
	The CoLT have helped me to improve the grade.	72	5	7	21	26	13	3.6	1.0
	I prefer to make exercises with CoLT.	72	9	11	14	22	16	3.4	1.3
1011AS	The CoLT have helped me to learn more.	98	9	11	28	37	13	3.4	1.1
	The CoLT have helped me to improve the grade.	98	9	7	20	43	19	3.7	1.0
	I prefer to make exercises with CoLT.	98	10	9	26	27	26	3.6	1.2
1011SS	The CoLT have helped me to learn more.	98	9	11	28	37	13	3.6	1.1
	The CoLT have helped me to improve the grade.	98	9	7	20	43	19	3.5	1.2
	I prefer to make exercises with CoLT.	98	10	9	26	27	26	3.4	1.2

"1" means completely disagree and "5" means completely agree. CoLT means Collaborative Learning Techniques.

Further work is planned to obtain a more accurate measure of the impact of collaborative learning and to spread their benefits. First, the corroboration of the presented findings by replicating the collaborative learning techniques in samples with a longer follow-up, in order to obtain the mean comparison corrected by the design effect. Another goal is the extension of the Learn-SQL system that currently supports *Laboratory classes* to support collaborative learning also in these classes. Finally, the study of other collaborative learning techniques that could also improve the learning process will continue.

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