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Impact of Teamwork on Academic Performance of Engineering Students*

ANA FONSECA REYES
Department of Mechanical Engineering, Universidad del Norte, Km.5 Vía Puerto Colombia, Barranquilla, Colombia.
E-mail: fonsecama@uninorte.edu.co

LUCENY GUZMÁN
Department of Industrial Engineering, Universidad del Norte, Km.5 Vía Puerto Colombia, Barranquilla, Colombia.
E-mail: lguzman@uninorte.edu.co

ÁNGELA JASMÍN FONSECA REYES
Institute of Human Sciences and Philosophy, Avenida Prof. Marcos Waldemar de Freitas Reis - Campus Gragoatá, Brasil.
E-mail: angelafonseca@id.uff.br

LIZETH DEL CARMEN GUTIÉRREZ PÚA
Department of Industrial Engineering, Universidad del Norte, Km.5 Vía Puerto Colombia Barranquilla, Colombia.
E-mail: gutierrezdl@uninorte.edu.co

The methods of collaborative learning are based on constructivism, understood as an equitable process, wherein each individual participates to produce a mutually desirable result, which promotes self-regulation. In this work, the influence of team-based learning (TBL) methodologies was studied. The effect of TBL on the learning of students in mechanical engineering and industrial engineering of the Universidad Del Norte, Barranquilla, Colombia, was analyzed. The investigation was carried out in the course of manufacturing processes for a sample of 348 students, specifically in the laboratory practice component, during three study periods. A quasi-experimental design was used, which involved three measurements: an individual quiz (IQ), a group quiz (GQ) and a final project (FP). The Comprehensive Assessment of Team Member Effectiveness (CATME) survey was used to determine perceptions of teamwork by students. Statistical analysis showed that the way in which TBL methodology is implemented develops students' skills influencing their academic performance and improving the scores obtained in assessment activities. Finally, students valued the contribution and interaction with their teammates as the most important aspects for team-based learning.

Keywords: feedback; learning methods; self-control; social interaction; spatial skills

1. Introduction

The training of engineering professionals requires the development of skills and knowledge in several industrial and scientific fields. For this reason, the promotion of methods that contribute to significant learning is essential in dynamic contexts so the future engineers can develop the skills that would allow them to make decisions, lead processes, be autonomous, and propose relevant solutions to the demands that they will encounter in professional practice. Traditionalist master methodologies show remarkable persistence in professional training in engineering. Faced with this problem, it is pertinent to question which pedagogical tools produce positive contributions to students' autonomous appropriation of the necessary concepts to practice their profession. Likewise, the question of how students perceive teamwork in their learning process should be asked.

To answer these questions, the authors of this work conducted research that evaluated the effects of team-based learning (TBL) methodologies for the study of manufacturing processes among mechanical and industrial engineering students at the Universidad Del Norte, Barranquilla, Colombia, in the laboratory practice component. For this, a rigorous theoretical revision was carried out that allowed different paradigms and pedagogical methods to be explored. Among these, the constructivist paradigm seems to be the most appropriate because it strengthens self-learning, bringing active and experiential knowledge to the fore.

This study explored the effectiveness of TBL methodologies for improving engineering teaching and learning, specifically in the study of manufacturing processes based on laboratory practices, chosen because in mechanical engineering, it is important to develop cognitive skills to be able to select appropriate materials and design correct molding and machining systems. Similarly, in the field of industrial engineering, leadership-related skills are required, as process control and optimization are. Collaborative work is key to the success of engineering projects and involves the development of skills such as leadership, planning and good group dis-

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tribution [1]. As a result, it was found that the two areas are related and require constant coordination and communication within a given business context. This supports the use of a TBL methodology for training engineers in manufacturing.

It should be noted that team-based learning has been practiced mostly in areas such as medicine [2–4] and business [5–7]; however, TBL remains a novel and scarce practice in engineering education [20, 21]. In addition, the implementation in the laboratory practice component between interdisciplinary groups, which allows gaining a profound understanding of how students traverse the learning process, and what challenges they encounter from their different roles and field of study.

In this research, a TBL methodology was implemented to allow students to acquire the theoretical foundations of the subject, enhancing their cognitive skills in manufacturing processes through laboratory practice and collaborative work in teams in order to promote arguments, based on theoretical principles and to make decisions, to support the development of each practice and projects implemented during the semester.

1.1 Collaborative Learning

Vygotsky [8], in 1934, argued that humans are socially and culturally constituted beings; therefore, learning is a cognitive process mediated by a social context. Thus, knowledge developed in interaction and exchange with other people produces a real internalization of knowledge, generating significant learning. Marton and Neuman [9] considered that knowledge and apprehension of concepts can be generated in environments of reflection and intersubjective reciprocity among people with common objectives. In this sense, collaborative learning can be understood as an equitable process, where each individual participates in producing a mutually desirable result. It is characterized by maintaining a distribution of responsibilities, joint planning of activities, and exchange of roles on a constant basis. Likewise, collaborative learning favors autonomy and self-regulation, which allow students to develop their own learning strategies and goals, as well as to foster their responsibility regarding what and how to learn. Here, the teacher's role is to provide ongoing support and promote communication and reciprocity related to the goal as a whole, helping to develop metacognitive practices on a personal and team level with the use of feedback. In this way, each student can learn at an individual pace and reflect on the need to create new strategies to improve performance and learning [10].

The research approach of the team of Gargallo, Ramón, Sahuquillo, Verde and Jiménez [11] applied in a course on the theory of education, taught to pedagogy and social education students at the University of Valencia demonstrates the effectiveness of collaborative methods. This experience allowed them to help their students to take an active role in the classroom, defining the routes their learning took and committing to curriculum development for the joint construction of knowledge. The strategies employed focused on the autonomous work of students based on specific issues, work in small groups oriented toward consensus, and instructor discussion and feedback. This produced better results in lessons and enabled motivational acceptance of the methodology by the students. Likewise, in a study by De Hei, Admiraal, Sjoer and Strijbos [12], with undergraduate students in primary education from universities in the Netherlands, the relationship between the use of group learning activities (GLAs) and learning outcomes perceived by the students were evaluated. The authors reported that the most common strategy used in the implementation of collaborative learning in higher education is the GLA, which they define as "curricular activities, in which students work on a collaborative project for a period of time greater than one lesson" [12]. Seven GLAs were included in their study, and two more were used over two academic years of the degree program. Subsequently, the instructors provided course documents related to the GLAs, and interviews were conducted with the students to evaluate their implementation and design. The results indicated the importance of directing the design of GLAs toward the generation of student engagement and interaction as these mediators contribute to learning outcomes in a significant way.

Another study, by Curşeu and Pluut [13], with students from the business studies program at a Dutch university sought to show the effects of collaborative learning in groups as learning entities. The results showed that students tend to learn more easily from their knowledgeable and more motivated peers than from their teachers. The methodology consisted groups of three to seven members, who each worked for seven weeks. Each group wrote three group tasks and collaborated to solve various cases in interactive conferences during a first-year organizational behavior course. It was found that leadership contributed greatly to cognitive activity, encouraging group discussion through the planning and coordination of group activities.

Nonetheless another study, by Gargallo, Sahuquillo, Verde and Almerich [14] found evidence that the success of the perspective of deep learning developed by Biggs [15] in the process of learning and appropriation of knowledge is motivated by the intrinsic desire to study to update the interest and competence of particular academic subjects through wide reading articulated with relevant prior knowledge.

1.2 Conceptualization and TBL Methodology

Michaelsen [16], the creator of the concept of TBL in 1979, explained it as a series of practices that support each other to achieve an effective instructional process, emphasizing that the main objective of this methodology is to pass beyond the idea of simply covering the contents of a class to focus on the application of concepts to solving problems. Thus, TBL is an effective pedagogical method in which the autonomy and participation of students is strengthened, reducing the time spent in the previous preparation of the class and the contents to be developed in working groups. Similarly, TBL can enhance critical thinking skills by exposing thought patterns within small groups to constructive criticism [17].

When carried out appropriately, TBL encourages the active participation of students who must interact collaboratively, thus achieving an exchange of perspectives and a combination of different skills, helping create organizational models and leadership that are reflected on the autonomous construction of knowledge. Walton [18] found that group work has the particular merit that "all participants have the opportunity to participate, and each one sees for himself the impact of the views on the other members of the group." It implies communication between participants, in which students are challenged to argue, express their opinions clearly, and value their peers' contributions, as well as their own; therefore, TBL can increase the deep focus of learning.

Hrynchak and Batty [17] explained that TBL is best understood as a constructivist methodology that encourages active and experiential teaching–learning processes which generally take place in three phases. These begin with an individual activity, followed by group work, where the Immediate Feedback Assessment Technique (IF-AT) [19] format is used, and it ends with the resolution of a case that seeks a transfer of knowledge with monitoring of by the teacher to generate the necessary feedback. During the execution of these processes, the teacher plays a constant accompanying role, which materializes in the feedback to the achievements of the students while they maintain a participatory and dynamic role that contributes to improving the appropriation and application of knowledge inside and outside the classroom, thus generating significant learning [20]. TBL methodologies have the advantage that students' conceptual knowledge is applied through a sequential line going to among individual work, teamwork, and immediate feedback. This is an economical and effective strategy that facilitates the achievement of learning outcomes, allows the development of critical thinking and teamwork skills, and tends to improve the academic performance of students [17].

An examination of the history of TBL shows that it has evolved and is now a validated teaching method, accepted in many disciplines in several countries around the world. Kibble, Bellew, Asmar and Barkley [21] report the following structure:

- team building, which usually lasts an entire class period;
- pre-class preparation by students;
- immediate feedback;
- exposure of problem situation;
- application of the 4 Ss: Significant problem, Same problem, Specific choice, Simultaneous reporting;
- establishing incentives; and
- peer review.

Multiple investigations have examined TBL in the instruction of different areas of knowledge. In the health sciences, for example, studies have been reported that indicate that after the implementation of TBL, students at lower academic levels receive greater benefit than the students who usually have superior grades. In this way, the general level of approval and satisfaction increases. In the same way, most medical educators have found that TBL provides an authentic and effective experience for resources relating to work in teams and addressing real-life clinical situations [2–4].

Research in business studies has shown that this type of methodology improves the inclination of students to achieve learning outcomes through interaction with their team members. Thus, TBL is implemented with support from social networks, case studies, and simulations that allow the application of economic theories to real-world situations [5–7].

Similarly, studies of the implementation of TBL in engineering have been conducted; their results are also satisfactory, although to a lesser extent. Wang and Mott [22] incorporated TBL methodologies in their engineering instruction of first-year students at the University of Arizona. More than 86% of the student participants demonstrated positive results, such as obtaining a satisfactory score in lesson evaluations or reporting a recognition of the importance of teamwork. The authors also indicated corroboration that TBL has equitable effects that do not distinguish on the basis of gender, race, or level of education. Thus, TBL has had success in instructional contexts. At the University of British Columbia, Van der Loos, Hendrik and Ostafichuk [23] implemented TBL in specific areas of mechanical engineering, such as mechanical design, that encountered high levels of student disapproval. Their implementation prompted a re-evaluation of the amount of material presented, the number of students in each course, and feedback tools. The resulting changes improved student–teacher communication and, thus, increased students' learning skills as they moved forward in their engineering courses.

Likewise, another study carried out by Najdanovic-Visak [24] at the University of Lancaster implemented TBL in a course for first-year students of seven engineering programs in order to assess the benefits and perceptions of students to teamwork technique. The results showed that TBL improved the students' learning process and increased their integration and reciprocity of knowledge during the class, and their perception of teamwork indicated that they recognize the importance of cooperative skills for full professional development, so this supports the implementation of this methodology in the field of engineering. On the perception of students towards team-based learning methodology, Matalonga, Mousqués and Bia [25], carried out a study at the Universidad ORT Uruguay, where TBL was implemented in two software engineering courses. The results were analyzed through a survey and showed that students have a positive perception of the TBL course in contrast to those traditional courses: they expose feel less stressed out before an assessment, high satisfaction towards the course despite receiving an increase in time and work that must be invested in the subject.

2. Methodology

A quantitative research design was used, with a quasi-experimental approach to the analysis of the effect of the implementation of TBL methodologies to the study of manufacturing processes in the laboratory practice component. The effects were analyzed in terms of the academic performance of the students and their perceptions of the application of TBL. Three tools were used to measure their performance: an individual quiz (IQ), a group quiz (GQ), and a final project (FP). Previous studies in engineering courses showed that most students perceive that collaborative projects are effective and enjoy the teamwork experience, and the analysis of these perceptions allows to improve the proposals for teamwork based on the needs of the students and even the teacher himself [26]. The Comprehensive Assessment of Team Member Effectiveness (CATME), created by Loughry, Ohland, and Moore [27], was used to evaluate perceptions of teamwork. This instrument contains a set of tools that allows teachers to implement best practices in the effective management of teamwork.

To analyze the results of the implementation of TBL, the statistical techniques described below were considered. In cases where hypothesis tests were performed, a significance level of 0.05 was used.

- *Analysis of variance (ANOVA)*: This technique based on the total variance in a particular variable is partitioned into two components: the component between groups and a component within groups. The F-ratio calculated as the ratio intra-group variance and the within-group variance are used to analyze the differences among group means. ANOVA has associated a p-value that indicates whether or not there are differences between the means. Values less than 0.05 indicate a statistically significant difference between the group means. On the contrary, it indicates that there are no differences.
- *Fisher's least significant difference (LSD) test*: This method is used as a follow-up to ANOVA to detect differences between the means of at least two groups of data.
- *Bivariate bar diagrams*: These are graphs that help visualize the behavior of a quantitative variable, taking into account the categorical variables.

2.1 Sample

The TBL methodology was implemented over three instructional periods in the subject of manufacturing processes, identified as PI, PII, and PIII. The students were in their fourth semester of the mechanical engineering (MEG) and industrial engineering (IEG) courses at Universidad Del Norte, Barranquilla, Colombia. This is a three-credit subject, with an intensity of two theoretical hours and two practical or laboratory hours per week the grade for this subject is assessed with two midterm exams and a final exam with a weigh of 20% each, laboratory practices 15%, and a FP corresponding to 25%. The implementation of TBL was considered through the assessment of laboratory practices and the FP. The analyses took into account the control group (49 students) corresponding to 4 laboratory courses that did not implement the TBL methodology and the experimental group (348 students) corresponding to approximately 23 laboratory courses who did implement it.

2.2 Instruments

TBL was implemented in the laboratory practice session, where students perform experimental tasks, such as casting, plastic deformation, and machining to deliver a project (manufacturing part) at the end of the course as a product. To identify the effects of the TBL methodology, a quiz in week 8 of the 16-

week course was used to collect the results from the more mature groups for decision making and teamwork.

The quiz contained five multiple-choice and single-answer questions, initially presented to individuals (IQ) and then to groups (GQ) in the same class session. The design of the questions related to *case studies* that an engineer may encounter in the work context and the degree of difficulty of the questions were chosen to prompt debate in the groups before the answer was chosen. The multiple response options for each question had a level of probability of being selected; however, to choose the correct option, it was necessary to have well-defined arguments and prior knowledge. For this, the IF-AT format was used, which incorporates scratch-off boxes and only under one box the star symbol appears indicating the correct option. the correct option [27]. Once the group members reach an agreement on the answer chosen, they proceed to scrape it into the format. If the star appears on the first attempt, the question score would be the maximum (1 point). If they fail, on the second attempt the rating decrease by 0.25 points.

Likewise, the FP was taken as an instrument, where the students were given the objective of creating a machined piece of aluminum with certain technical specifications as a product of the manufacturing processes carried out during the semester. Two engineering professors with experience in manufacturing formed the evaluation team. These used the rubric of performance and problem solving that appears in Table I to evaluate the student products.

Finally, the CATME with peer evaluation and self-evaluation criteria was used, according to the following components, indicated by Loughry, Ohland, and Woehr [28]: interacting with teammates (I), contributing to the team's work (C), keeping the team on track (K), expecting quality (E), and having relevant knowledge, skills, and abilities (H).

2.3 Procedure

To carry out TBL in the instruction of manufacturing processes in the laboratory practice component, the following steps are described:

- *Design study material*: Laboratory study was carried out using a guide; the contents indicated the steps to carry out the experimental activities and a series of questions to be resolved after execution. With the implementation of TBL, it was necessary to redesign the laboratory guides in the following ways.
  - Objectives of the practice: Objectives were phrased precisely to indicate to the students the knowledge that was required for the development of the practice. For example, "Knowing the process of foundry molding," "Identifying variables that influence the process of making a foundry," and "Identifying defects associated with the molding and casting processes". This, considering that students tend to be more committed to goal setting, planning, and teacher control and monitoring [29].
  - Previous knowledge: In this section, the theoretical basis of the specific knowledge of the practice to be developed were presented. Further, bibliographic sources, videos, and support blogs were referenced to bring students sufficient information to be ready for the class. At the end of this session, two or three questions were added to check the students' understanding of the presented material. Students should have approximately 1.5 hours to read and understand the basics of the practice (Fig. 1a).
  - Practice procedure: Here, the steps required for the objectives of the practice to be reached are broken down to allow results to be obtained that could help analyze the processes.
  - Analysis of the results: In this stage, questions and problems were designed focused on the analysis of the results obtained through practical experiments and the theoretical basis that had previously been acquired.
- *Group formation*: Each laboratory course had approximately 15 students, so 4 groups were formed for each course. A condition for the formation of the groups was the heterogeneity of the academic specialties (mechanical engineering and industrial engineering). The team-building process was followed to benefit the future functioning of the groups [30]. Four students were selected randomly to act as leaders for the groups; then, the mechanical engineering students were randomized because they were a minority compare to the industrial engineering students (generally in 1/3 ratio), and the others were distributed using a didactic roulette procedure, implemented by the website https://www.classtools.net/random-name-picker/. Socialization and exchange of personal and academic experiences occurred. This was done to encourage teamwork in groups and reduce the fear of interacting with peers in a way that was different from the usual. Finally, the required characteristics of teamwork, namely, common objectives, leadership, communication impulse, problem solving, motivation, and interdependence emerged [31].

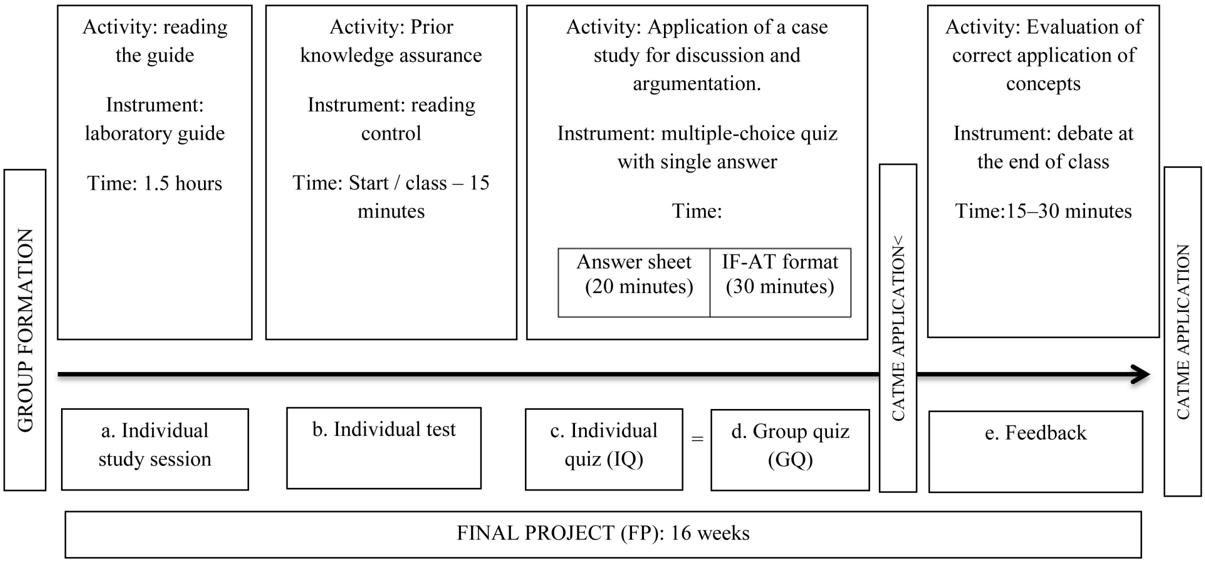

Fig. 1. Sequence of TBL in instruction of manufacturing processes, specifically laboratory practice.

- *Reading control*: For each class session, the reading and understanding of the guide was verified through open questions, and their socialization in small groups was observed prior to the development of each practice. This activity would take 15 minutes approximately from the beginning of the class (Fig. 1b).
- *Quiz application*: During the eighth week of the academic period, the IQ containing the case study on manufacturing processes was given to each student. Those had 20 minutes to solve it on an answer sheet (Fig. 1c). Subsequently, the groups joined and answered the same questionnaire as the GQ. In this context, students were asked to discuss their ideas, defend their positions with arguments and reach a consensus using the IF-AT format (Fig. 1d), which would finally indicate the correct answer to each question.
- *Feedback*: At the end of the administration of the GQ, students already knew their level of success and were able to self-assess their individual and team performance. At the end of the period, a discussion was held with the class together to identify the successes and failures in the answers. At this point, the instructor intervened to address concerns, justify the correct answers, and explain the reasoning to prevent incorrect interpretations of the subjects being studied (Fig. 1e).
- *CATME application*: The survey was applied in two moments: intervention 1, after the feedback of the GQ and intervention 2, after the evaluation of the FP. This to know the persecution and evolution of the teamwork of the students during the study period.

3. Results

3.1 Academic Performance Results

Student performance was examined based on four statistical analyses. These analyses considered the score in the activities IQ, GQ, and FP, in the three consecutive academic periods of PI, PII and PIII. For each activity, the student gets a score between 0.0 (minimum) and 5.0 (maximum), following the scale stipulated in the Uninorte Student Regulations [32]. In addition, an evaluation rubric was designed to identify the student performance level, in relation to the achievement of the learning objectives (Table 1). The analyses were carried out without discriminating by periods since there were no significant differences in the scores of each activity by period.

Table 1. Relationship between qualification and performance level

Rating range	Performance level	Degree achieved
[0,2)	Not satisfactory	The student does not justify or argue why and what is studied or investigated the manufacturing process.
[2,3)	Developing	The student justifies and argues unclearly and inconsistently why what is studied or investigated a manufacturing process.
[3,4)	Satisfactory	The student justifies and argues clearly and coherently why what is studied or researched a manufacturing process.
[4,5]	Exemplary	The student justifies and argues clearly and coherently why what is studied or investigated a manufacturing process and relates it to an example.

Table 2. Analysis of variance for scores by activity

Sources	Sum of squares	Degree freedom	Middle squares	F-ratio	p-value
Between groups	442.006	2	221.003	307.89	0.0000
Within groups	747.233	1041	0.717803		
Total	1189.24	1043			

Table 3. Least significant difference test for activity means

Activity	Cases	Means	Homogeneous groups
IQ	348	2.64	X
FP	348	3.94	X
GQ	348	4.09	X

Analysis 1. In the first analysis, the scores obtained by the students in the activities: IQ, GQ and FP were compared through a one-factor ANOVA (Table 2). The p-value found by the F-test was less than 0.05. This indicates that there was a statistically significant difference between the means of the three activities. To determine which means are significantly different from others, the LSD test was performed. The results of this test indicated three heterogeneous groups. Table 3 presents the more usable results for the scores of the FP with respect to the IQ. This seems to indicate that students improved in skills related to the acquisition of knowledge, cognitive strategies, and effective communication within their work teams (Fig. 2). This may be due to the teacher's guidance during the methodology implementation and the commitment of the students. To better visualize the results for the students, a second analysis was carried out.

Analysis 2. The results of the three activities were analyzed according to the performance levels defined in Table 1. For this, students were grouped at unsatisfactory and developing levels, and students at satisfactory and exemplary levels, respectively. Fig. 3 shows the bivariate bar graph for these clusters. In the first activity (IQ) only 46.3% of the students were at satisfactory and exemplary levels, but this percentage increased in time until it reached 96.8% in the third activity (FP). These results seem to indicate that the instructor's relationship with the students, the feedback, and the sharing of responsibilities and tasks with classmates had an impact on the final results of the course; also, it was found that the process of strengthening TBL unfolded gradually over time.

Analysis 3. An ANOVA was used to compare the scores in the FP of the groups where TBL was implemented (experimental group) and where it

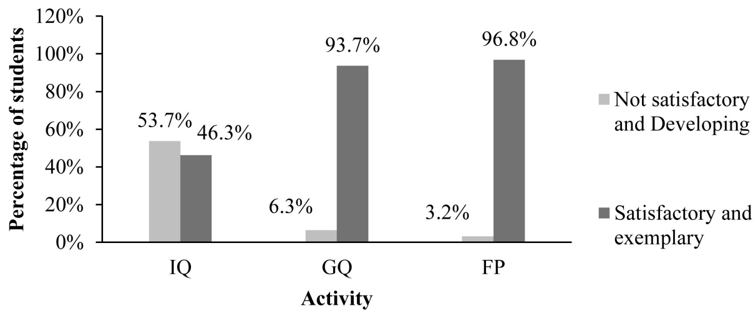

Fig. 2. Percentage of students by activity and grouped levels.

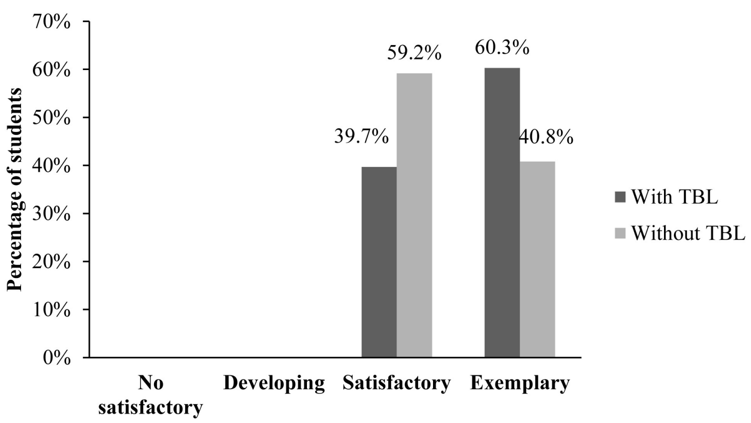

Fig. 3. Percentage of students in performance levels with and without TBL.

Table 4. Analysis of variance for the score by implementation

Sources	Sum of squares	Grades	Middle squares	F-ratio	P value
Between groups	0.611718	1	0.611718	4.24	0.0402
Within groups	54.3902	377	0.144271		
Total	55.0019	378			

Table 5. Least significant difference test for means

Implementation factor	Cases	LS means	Sigma LS	Homogeneous groups
Without TBL	49	3.88	0.0543	X
With TBL	330	4.00	0.0209	X

Table 6. Analysis of variance for the final project assessment by specialization

Sources	Sum of squares	Grades	Middle squares	F-ratio	P value
Between groups	3.4052	1	3.4052	15.91	0.0001
Within groups	74.061	346	0.2105		
Total	77.466	347			

Table 7. Least significant difference test for medium activities and specializations in mechanical engineering and industrial engineering

Activity	Course	Cases	LS means	Homogeneous groups
IQ	MEG	121	2.59	X
	IEG	227	2.65	X
GQ	MEG	121	4.19	X
	IEG	227	4.04	X
FP	MEG	121	3.80	X
	IEG	227	4.01	X

Note: MEG, mechanical engineering; IEG, industrial engineering.

was not implemented (control group). Table 4 summarizes the results. The p-value obtained tests the statistical significance of the implementation factor on the scores. The LSD test corroborated the difference between the means. The results are illustrated in Table 5; better scores are observed in the experimental group.

Fig. 3 shows the percentage of students for each of the performance levels for those who implemented TBL and for those who did not. It is noteworthy that in none of the cases were students found at the two lowest levels, but the percentage of students at the highest level was greater with the TBL implementation in relation to those who did not implement it. The students who participated in the TBL methodology obtained better scores in FP than those who did not participate. 60.3% of those who participated were at exemplary level against 39.7% of those who did not participate.

Analysis 4. It was investigated whether TBL implementation had a different influence on the performance of MEG and IEG students. ANOVA indicated significant differences only for the FP, as illustrated in Table 6. The comparison of means for the students in MEG and in IEG in the three activities is summarized in Table 7. This table shows a significant difference for the FP results that is not significant for IQ or GQ. However, it

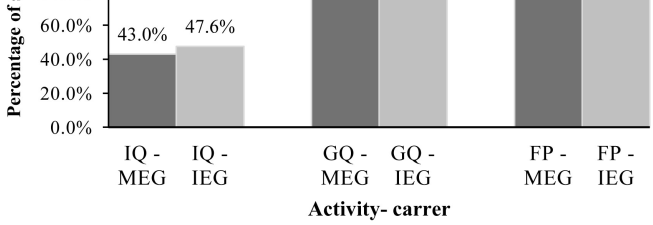

Fig. 4. Percentage of students at satisfactory and exemplary performance levels in all three activities, by specialization.

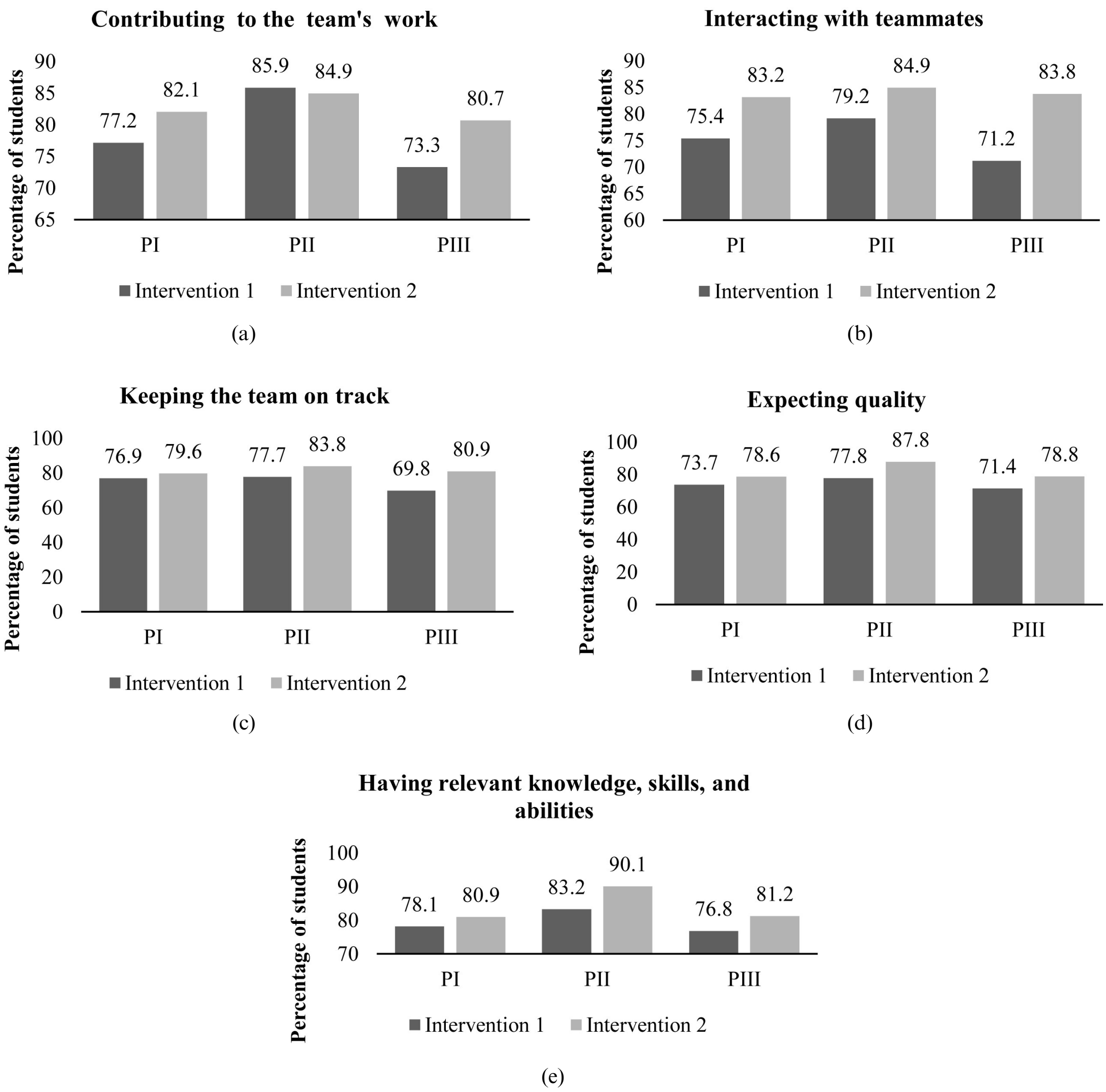

Fig. 5. Percentage of students who rated given CATME categories at 4.0 or 5.0

should be noted that the students' results were better for the GQ than in the individual activity, which indicates that the interactions that arise in teamwork have a positive effect on academic performance.

Fig. 4 illustrates the percentages of students who obtained satisfactory or exemplary performances in the MEG and IEG programs in each of the three activities. These values support the results of the LSD means test.

3.2 Results for Student Perception

The students evaluated their participation and that of their co-workers through the CATME survey on the activities proposed and developed in class. The evaluation was carried out in five categories that evaluate teamwork: contributing to the team's work (C), interacting with teammates (I), keeping the team on track (K), expecting quality (E), and having relevant knowledge, skills, and abilities (H). The evaluations were on a scale of 1.0 to 5.0. Fig. 5 illustrates the percentage of students who rated 4.0 and 5.0 for each of the categories considered by CATME in the intervening periods.

During each period, two interventions were carried out; one after the feedback of the GQ and another after the evaluation of the FP; the purpose was to observe changes in the students' perceptions as TBL continued to be applied during course development. It should be noted that for each period, the second intervention featured a higher percentage of students who reported scores of 4.0 or 5.0, indicating that their perception of what teamwork can offer improved, and they assigned greater importance to interaction with peers and to the contribution of teamwork to remaining responsible students, achieving proposed objectives, and seeking quality products.

4. Discussion

Differences were found between the academic results of the students in the three activities (Table 2), they were improved when the students worked as a team (Table 3). This is to be expected because in team work there is cooperation, discussion, and sharing of knowledge. However, this is positively reflected over time since the students have to apply what they have learned in the FP, carried out at the end of each period. It is also observed that the percentage of students at the top two levels in the assessment was greater in the final assessment than in the first two (Fig. 2). This reflects progress in the true understanding of teamwork, continuously accompanied by the teacher, maintaining the roles for each team, and the awareness of the students in self-regulating their learning process.

Taking into account that the FP activity measured specific learning objectives for all the groups of the subject considered, it can be observed that the TBL methodology had a positive effect on student results (Table 4) because better results are achieved through it (Table 5), and the students were assessed at the higher level at a higher percentage (Fig. 3).

Better results were found for the final assessment among industrial engineering students than among mechanical engineering students (Tables 6, 7 and Fig. 4). This may be because in their training they study subjects related to development of the skill of working in teams to lead, organize, and coordinate groups.

The results showed that the implementation of the TBL methodology was positive, not only because of the level of student approval, but also in the perception of teamwork. According to the weights obtained by students in each of the categories of the CATME survey, it was observed that students considered teamwork in each category studied over time to be more valuable. For example, the average percentage of students who felt that contributing to the team's work (C) was valuable increased from 78.8% in the first intervention to 82.6% in the second one (Fig. 5a). In the category interacting with teammates (I), the average percentages changed from 75.3% to 84.0% (Fig. 5b). Keeping the team on track (K) changed from 74.8% to 81.4% (Fig. 5c). Expecting quality (E) obtained an initial percentage of 74.3% and a final percentage of 81.7% (Fig. 5d). Having relevant knowledge, skills, and abilities (H) obtained ratings of 4.0 or 5.0 among 79.4% of the students in the first intervention and 84.1% in the second intervention (Fig. 5e).

On the other hand, some limitations were observed; 6.3% of the students were assessed at the not satisfactory and developing level, in the GQ activity, and 3.2% persisted at the same level in the PF activity (Fig. 2). This may indicate that they would not have had a good communication, interaction, or collaboration, between team members. The resistance of some students to being part of new groups, different from the usual ones for long periods, can also be associated. The reasons for this phenomenon should be studied more rigorously in future interventions. Lastly, it may be worthwhile for future studies to explore other social contexts of regulation in areas after manufacturing processes to give continuity and to take advantage of the basis of self-regulation and knowledge of team-based learning.

5. Conclusions

This study investigated the effects of the TBL methodology on the performance of students on the subject of manufacturing in their laboratory component and identified the student's perception of the practices that can be implemented in team work. At the end of each period during which the methodology was implemented, statistical analyses were performed to measure its effect. Results indicate that the investigation successfully achieved the objective, taking into account that at the time of group formation, the students felt uncomfortable and antagonistic about working in groups that were not the usual social groupings. They were used to working in groups where friendship and camaraderie prevailed, and they were in a comfort zone that they did not want to leave. At the end of the course, after the implementation of TBL, the manufacturing processes students were satisfied with the achievements reached through the learning process and in teamwork, as evidenced in the responses to CATME.

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Ana Fonseca Reyes is a professor of the mechanical engineering department at Universidad del Norte (Barranquilla-Colombia), graduated in Metallurgical Engineering. A Master's degree in Metallurgy and Materials Science. Her research interests include engineering education, engineering materials, and electrochemical process. She has also worked in areas such as material sciences, manufacturing process and corrosion.

Luceny Guzmán Acuña is a professor of the industrial engineering department at Universidad del Norte (Barranquilla-Colombia), graduated in Mathematics and Electrical Engineering, with higher education in Statistics. A Master's degree in Industrial Engineering and a doctorate in the same area. Her research interests include engineering education, data analysis, optimization theory, game theory and optimization of renewable resources for electric power generation.

Ángela Jasmín Fonseca Reyes Bachelor of Science in Social Sciences (2013) from Pedagogical and Technological University of Colombia (UPTC), Master's degree in Education (2018). Second year student of PhD in Anthropology at Federal Fluminense University. Researcher of the Fluminense Nucleus of Studies and Research of the Fluminense Federal University (NUFEP / UFF) and the Institute for Comparative Studies in Conflict Management (INCT/InEAC). Experience in education of the social sciences.

Lizeth Del Carmen Gutierrez Púa is a fifth year Industrial Engineering student at the Universidad del Norte (Barranquilla, Colombia). Candidate for a Master's Degree in Mechanical Engineering at the Universidad del Norte, Materials Science Monitor and Research Partner. Her research interests include engineering education, data analysis, engineering materials, and materials science.