Chapter

A Method to Improve Comprehension and Learning in Science Education. A Case Study in Systems Engineering and Automation

Sergio Velázquez-Medina and Pedro Cabrera-Santana

Abstract

Difficulties are commonly detected in students with respect to the acquisition of certain specific competencies in a particular topic. One strategy to optimize the assimilation of knowledge and improve the learning results of students in a specific topic is through the use of the active learning process. Active learning can serve to facilitate autonomous and collaborative learning in specific topics as a complement to in-person classes. In this chapter, a method to improve comprehension and learning is developed and applied, using for this purpose both autonomous and collaborative works. The case study presented is undertaken for one of the subjects in the area of systems engineering and automation in one of the public universities of Canary islands (Spain). Different specific topics of the subject were selected. To check the effect of the application of the proposed method, a statistical analysis was performed. For this objective, *t*-test and the p-value statistical were used. As results, it was found that 100% of the students who presented some difficulty in relation to the general subject obtained higher relative results in the specific topics that they worked on when employing the proposed method, compared with their global result in the subject.

Keywords: integrated active learning, improve comprehension, autonomous learning, collaborative learning

1. Introduction

It is not uncommon to find that, for one reason or another, it is difficult to transmit certain knowledge of some subjects to the student, or that, because of the nature of such knowledge, its transmission entails certain difficulties [1–5]. In consequence, the skills derived from such knowledge may not be correctly acquired. In [3], a study of this question in relation to the particular case of students with difficulties in acquiring knowledge in topics related to energy conservation was undertook. They detected that students had difficulties in acquiring skills because of the presence of complex scientific concepts and because they found the topic to be monotonous. In [1], it was identified how the active learning process improves the cognitive engagement with concepts in the classroom.

Autonomous learning, accompanied by a close follow-up on the part of the teacher, is one of the strategies that can be used to achieve better learning results in certain specific topics and to optimize skills acquisition [2, 6–11].

In [11], the importance of autonomous learning was established, defining it as a process in which the individual takes the initiative, with or without the help of others, in diagnosing the learning needs, formulating the learning targets and identifying the human and material sources required for the learning process. In [7], the importance of the developing skills in autonomous learning by engineering students is pointed out, as a way to support life-long learning. In [8], the feasibility and functionality of the implementation of autonomous learning in Pakistan are analysed, studying for this purpose the particular case of the teaching of English in four universities in the country. The professors concluded that the implementation of autonomous learning techniques helps to make students more self-sufficient. In the implementation process of the techniques they used, they observed different obstacles that arose as result of particular features of the education system in their country, cultural precedents and certain psychological aspects of the students.

When autonomous learning is assimilated by a student, it can subsequently be transmitted to the rest of the students as a collaborative learning strategy [12] and as a complement to the classes of the teacher. The benefits of collaborative learning include: development of higher-level thinking, oral communication, self-management, leadership skills, promotion of student-faculty interaction; increase in student retention, self-esteem and responsibility and a better understanding of diverse perspectives [13]. In [14], the collaborative problem-solving games into spatial dialogues in a virtual cellular biology game is explored.

Various techniques found within the framework of active learning processes can be used in collaborative teaching as alternatives to traditional processes [12, 15–19].

In [12], a particular case of the teaching of mathematics is studied as part of the Business Administration Degree at the International University of Catalunya (Spain). They had noted a certain lack of motivation on the part of the students with respect to this subject and began to use game-based learning (GBL) techniques with the aim of stimulating interest in it. According to the authors, the results obtained were very promising. In [19], how collaborative inquiry learning offers educators a context within which support can be found for the understanding of scientific-technological concepts is analysed. In their case study in the United States, they used both GBL and problem-based learning (PBL) techniques.

From the analysis carried out on the scientific publications found, it can be deduced that all of them make exclusively a qualitative analysis from their experiences. In addition, in their studies they use a single technique in the collaborative learning process, generally game-based learning.

An interesting and useful technique for the transmission of acquired knowledge to the rest of the students when the number of students is high, and/or when insufficient time is available in the in-person class, involves the making of mini-videos (less than 10 minutes long) in which each student transmits the knowledge they have acquired [20–23]. Supervised and monitored by the teachers, these videos can subsequently be published in a virtual environment, open to the other students, so that they can view them and use them as an educational complement.

In the study presented in the present paper, a specific method is developed within the framework of the active learning process. The method is applied to the particular case of the learning of a topic related to systems engineering and automation. The original contributions of this study are as follows:

a. In the phase of collaborative learning, three different techniques have been used

b. The degree of improvement attained by each student during the development of the activity was quantified. The cases in which the improvement was particularly high were identified.

2. Methods and materials

2.1 Method

Among others, the Center for Teaching Innovation of Cornell University [13] defines different basic aspects that need to be considered when establishing an innovative method related to active learning. With this in mind, and for the particular case study presented in this paper, the method developed by the authors is structured into four stages (**Figure 1**).

- Activity preparation stage
- Autonomous work stage
- Collaborative work stage
- Assessment stage of the success of the method

The activity that is developed will serve as a complement to the classroom teaching, and the active learning during the autonomous and collaborative work stages will serve as reinforcement for the students in the assimilation of competencies.

2.1.1 Activity preparation stage

At the beginning of the term, a clear description and explanation of the activity and its purpose are given to the students. The rules for participation in the activity and the marking criteria are explained (**Figure 1**).

For the case study, the activity was obligatory and the mark given to it corresponded to 5% of the total mark for the subject.

The teacher, after looking at the historical data on the topics and/or concepts that have commonly presented certain assimilation difficulties on the part of students, designs related work activities. The random formation of groups with a maximum of two students is proposed. Each group is then randomly assigned the task of preparing a series of concepts linked with one of the specific topics (hereinafter referred to as STO). Work on concepts related to the same STO can be assigned to different groups.

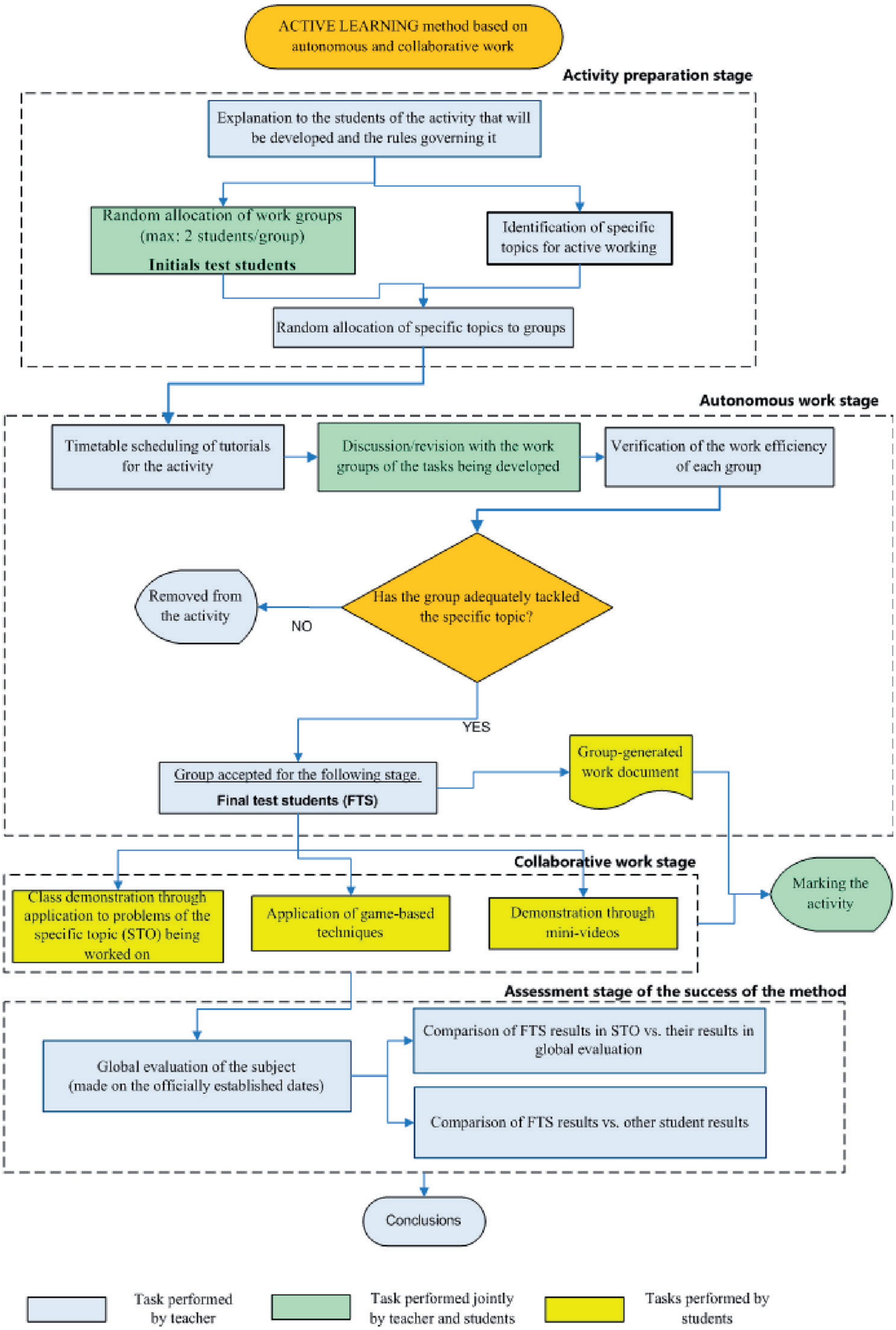

Figure 1.
Method applied to the case study.

Initially, in the case study, tasks linked to six STOs of the subject were assigned, ensuring that each STO was tackled by a minimum number of students.

For the development of the collaborative work stage, each group is assigned one of the following techniques: PBL directly in the classroom, the application of GBL directly with the rest of the students or the making of mini-videos with a maximum duration of 5 minutes which, after inspection by the teacher, are uploaded to the virtual environment of the subject in question to be shared with the other students who signed up for the subject.

2.1.2 Autonomous work stage

For the follow-up of the work of each group, the professor arranges voluntary tutorials at specific times and dates outside the teaching timetable.

For the case study, 4 h were allocated each week in the virtual environment for 15-minute sessions with each group should they require assistance with the task.

Each group can request a date and time through the virtual environment of the subject in question. In this stage, the professor monitors the work of each group to ensure the subsequent success of the collaboration stage, helping the students in the development of the required skills, the approach to typical problems, reflection techniques, etc. Any group that does not implement this stage in an appropriate way is removed from the activity and is given a mark of 0. The groups that perform this stage correctly advance to the collaborative work stage. Prior to commencement of the collaborative stage, the groups have to prepare and submit a document explaining the work that has been developed along with the guidelines they will follow for that stage. These documents are uploaded to the virtual environment of the subject in question which the other students will have access to.

2.1.3 Collaborative work stage

In this stage, each group has to transmit to the rest of the class the knowledge that they have acquired in the STO they have been working on. For this, they use the PBL, GBL or mini-video strategy. The mini-videos must be viewed individually by the other students in the class. This latter strategy is particularly useful when there are time restrictions and/or a large number of students have signed up for that particular subject.

2.1.3.1 Marking the activity

The student must have advanced to the collaborative work stage for the work developed to be evaluated and awarded a mark. The weight of the mark given is evenly split between the assessment of the professor and the assessment of the other students in the class (except for the second member of that student's work group). The mark given should take into consideration the document presented in the autonomous work stage as well as the activity developed in the collaborative work stage (see **Figure 1**).

For the assessment made by the students themselves of the work of their classmates, a questionnaire has been developed using a five-point Likert scale [24]: 1: Very poor; 2: Poor; 3: Sufficient; 4: Good; 5: Excellent. Aspects such as the following should be evaluated:

- The effort made by each group in the activity

- The clarity and the methodology followed in the work during the collaborative work stage.

2.1.4 Assessment stage of the success of the method

Finally, for the evaluation of the success of the method, the results from three of the six STOs were used. The groups which participated in the three STOs which were discarded had not performed the task in the prescribed manner (**Figure 1**). The students who worked on the selected STOs are given the name of final test students (FTSs).

The data considered for the assessment of the success of the method applied to the case study are the results obtained in the official examinations and on the official dates for the subject in question. For the purposes of the assessment, this official examination should clearly differentiate between the different STOs worked on in the learning activity, allowing a mark for all students for each STO as well as a global mark in the subject.

The following data are analysed in the assessment of the success of the method:

a. Comparison of the global mark obtained by each FTS in the official exam of the subject with the mean global mark of all the students.

b. Comparison of the mark obtained by each FTS in the official exam in the STO on which the FTS worked with the mean mark of all the students.

c. Comparison of the relative grades of each FTS obtained in the STO that the FTS worked on and in the global subject.

2.2 Materials

One of the subjects taught in the School of Industrial and Civil Engineering as part of the Industrial Organization Engineering Degree is Control Engineering. Within the structure of the degree course, it is considered part of the 'Automation' material. The degree comprises four academic years of two terms each, with a total of 240 ECTS (European Credit Transfer and Accumulation System) credits [25]. The Control Engineering subject is given in the second term of the third year of the course.

The degree meets all the official teaching regulations in Spain and has been subjected to and passed an evaluation process in accordance with the protocol established by the corresponding State and Autonomous Community agencies. It additionally complies with the quality criteria and standards established by the European Association for Quality Assurance in Higher Education (ENQA) [26] and is registered in the Spanish Registry of Universities, Centres and Qualifications (Spanish initials: RUCT) [27]

The so-called Verification Report (Memoria de Verificación in Spanish) is the reference document for each official qualification in the Spanish state. The document includes the objectives, competencies, academic structure, available resources, etc. for each qualification, including the reference degree of the present case study. In point 2 of the corresponding Verification Report, the competencies associated to the degree in question are listed, the following of which can be highlighted:

- Transversal competency G6: 'AUTONOMOUS LEARNING. Detecting deficiencies in one's own knowledge and overcoming them through critical reflection and choosing the best option to extend this knowledge'.

This competency is associated to the reference subject in its corresponding Teaching Programme.

The case study considered in the present paper was undertaken for the aforementioned subject of Control Engineering during the 2018/2019 academic year. The number of students included in the initial stage of the trial was 37, with a total of 20 groups being formed (see **Figure 1**). As an additional tool, the virtual work environment of the reference university was also used for the management of the activity.

3. Discussion of the results

Following the criteria established in the methodology (see section 2.1.4), a total of 17 students advanced to the collaborative work stage and were thus considered FTSs. These 17 students worked on three of the STOs that were initially proposed in the activity. **Table 1** shows the STOs that were finally evaluated and the corresponding number of FTSs.

Figure 2 shows the results of the comparison of the marks obtained by each FTS in the global examination of the subject with the mean mark obtained by all the students. It can be seen that some of the FTSs had general difficulties in assimilating concepts of the subject, while others appear to have found it easier.

Figures 3–5 compare the mean grade obtained by each FTS in the specific parts of the global exam concerning the three STOs that were worked on with the mean grade of all students in the same STO. In general terms, it can be seen that whereas a total of 7 FTSs scored below the mean grade in the global exam of the subject (see **Figure 2**), for the case of the results in the STOs, only two of these (FTS-1 and FTS-5) were awarded a grade below the mean value of all students.

To better evaluate the improvement in the results of each FTS as the result of the application of the method developed in the present paper, the so-called relative grade (RG) metric was used (Eq. 1):

ID specific topic	Description	ID of the FTS
STO1	Stability of the response of dynamic systems. Root locus	FTS-1 to 7
STO2	Applications of control actions in industrial processes. PID control	FTS-8 to 11
STO3	Dynamic systems modelling	FTS-12 to 17

Table 1.
Description of specific topics (STOs) worked on by the final trial students (FTSs).

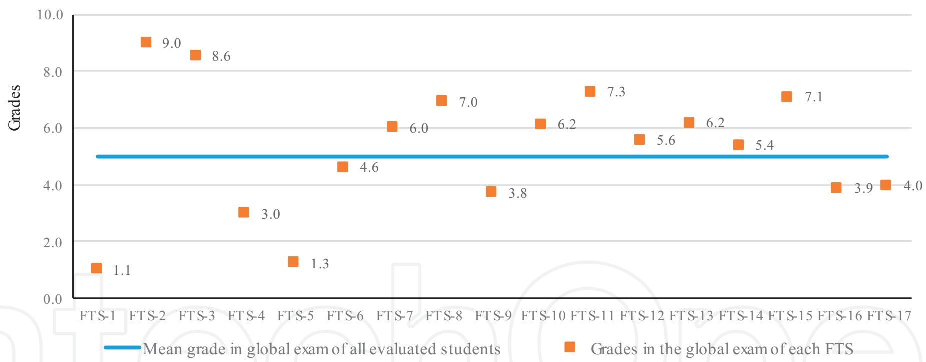

Figure 2.
Comparison of the grade of each FTS in the global exam with the mean grade of all students (minimum grade of 0 and maximum of 10).

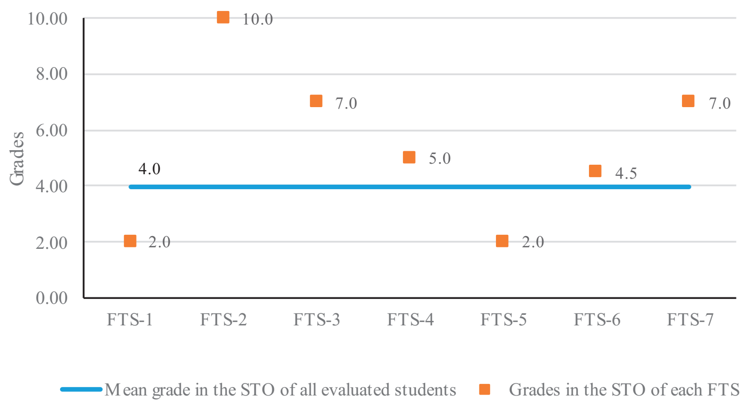

Figure 3.
Comparison of grade awarded in STO-1 by each FTS with the mean grade of all students ((minimum grade of 0 and maximum of 10).

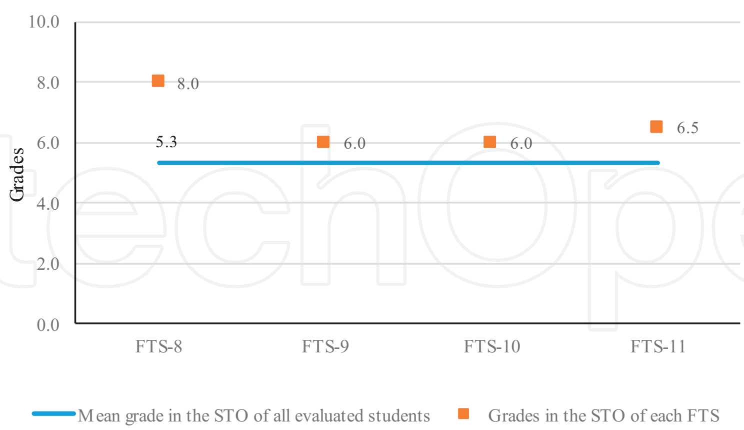

Figure 4.
Comparison of grade awarded in STO-2 by each FTS with the mean grade of all students ((minimum grade of 0 and maximum of 10).

$$RG = \frac{G\_FTS_i - \overline{Grade}}{\overline{Grade}} \tag{1}$$

where G_FTS_i is the grade obtained by each FTS, and $\overline{Grade}$ is the mean grade of all the students who sat the exam.

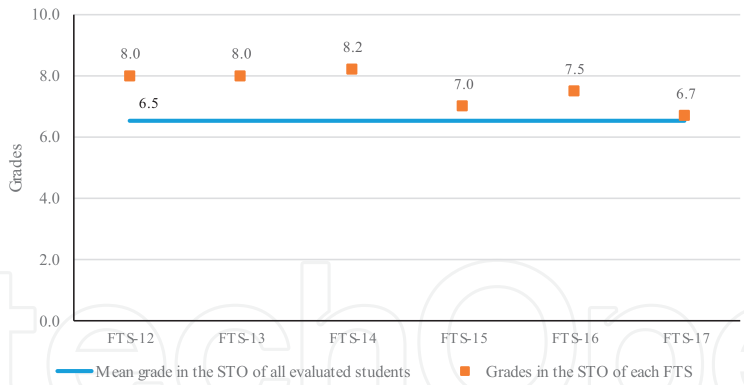

Figure 5.
Comparison of grade awarded in STO-3 by each FTS with the mean grade of all students ((minimum grade of 0 and maximum of 10).

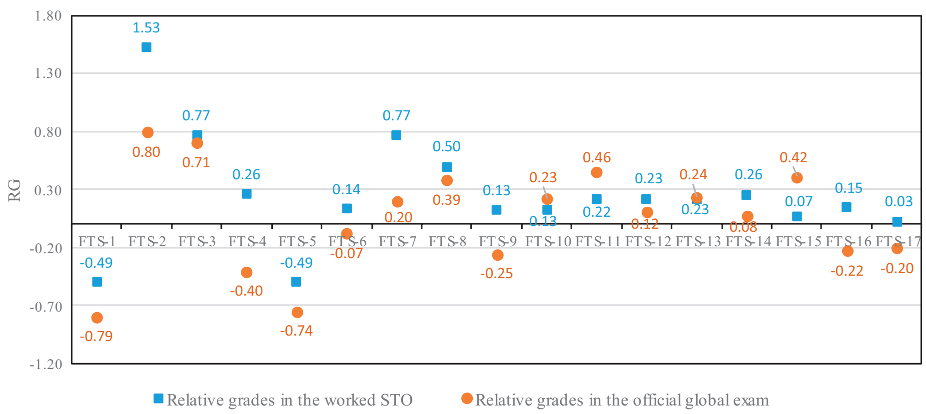

Figure 6.
Comparison of relative grades for each FTS.

Figure 6 compares the RGs for each FTS obtained in the global exam (**Figure 2**) with those obtained in the different STOs (**Figures 3-5**). It can be seen that 13 of the 17 FTSs improved their relative results as the result of the application of the innovative educational method developed. It should be highlighted that all the FTSs who had difficulties with the assimilation of concepts of the general subject (FTSs with values of RG<0 in the official global exam) improved their RGs in the STOs that they worked on.

Statistical analysis is performed to check the effect of the application of the proposed method. Since we want to evaluate the degree of association or independence between a quantitative variable and a categorical variable, the inferential statistical procedure resorts to comparing the means of the distributions of the quantitative variable in the different groups established by the categorical variable. Being this dichotomous, *t*-test with a significance value of 0.05 was used. Further, the parametric requirements are met, such as the normal distribution of the quantitative variable in the groups that are compared and the homogeneity of variances in the populations from which the groups come [28].

First, it was evaluated the difference between the results obtained for the RG in the worked STO with those in the official global exam (**Figure 6**). These values were compared with a null hypothesis where that difference was less than or equal to zero. So, it obtained a *p* value of 5.4E-3. This indicates that student improve their results when the proposed method was applied.

4. Conclusions

After application of the method developed in this paper, student assimilation of competencies which had historically presented certain difficulties improved in general. A total of 88.2% of the final test students (FTSs) who used the proposed method obtained higher grades in the specific topic they were working on than the mean grade of all the students. In addition, 76.5% of the FTSs obtained a higher relative grade (RG) in the specific topic they were working on with the proposed method than the RG they obtained in the global exam of the subject, with this value rising to 100% in the case of FTSs with the highest difficulty in the subject (with an RG<0 in the global exam).

The p value obtained in the statistical analysis guarantees the results obtained with the proposed method. It can be applicable to subjects in any branch of science, as a way to improve the assimilation of competencies that students tend to have difficulties with.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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References

[1] Wu SPW, Van Veen B, Rau MA. How drawing prompts can increase cognitive engagement in an active learning engineering course. Journal of Engineering Education. 2020;**109**:723-742

[2] Martínez-Rivero MD, Hernández-Castellano PM, Marrero-Alemán MD, Suárez-García L. Material didáctico sobre la selección de procesos de fabricación. In: V Jornadas Iberoamericanas de Innovación Educativa en el Ámbito de las TIC y las TAC. 2018

[3] Szu-Wei C, Chih-Hui Y, Keng-Shiang H, Shen-Li F. Digital games for learning energy conservation: A study of impacts on motivation, attention, and learning outcomes. Innovations in Education and Teaching International. 2019;**56**(1):66-76

[4] DeLisi J, Kook JF, Levy AJ, Fields E, Winfield L. An examination of the features of science fairs that support students' understandings of science and engineering practices. Journal of Research in Science Teaching. 2021;**58**:491-519

[5] Voon XP, Wong LH, Looi CK, Chen W. Constructivism-informed variation theory lesson designs in enriching and elevating science learning: Case studies of seamless learning design. Journal of Research in Science Teaching. 2020;**57**:1531-1553. DOI: 10.1002/tea.21624

[6] Gerard L, Wiley K, Debarger AH, Bichler S, Bradford A, Linn MC. Self-directed science learning during COVID-19 and beyond. Journal of Science Education and Technology. 2021;**31**:258-271. DOI: 10.1007/s10956-021-09953-w

[7] Marra RM, Hacker DJ, Plumb C. Metacognition and the development of self directed learning in a problem-based engineering curriculum. Journal of Engineering Education. 2022;**111**:137-161. DOI: 10.1002/jee.20437

[8] Musarat Y, Farhat N, Isamar CM. Teacher-directed learning to self-directed learning transition barriers in Pakistan. Studies in Educational Evaluation. 2019;**61**:34-40

[9] Oddone K, Hughes H, Lupton M. Teachers as connected professionals: A model to support professional learning through personal learning networks. The International Review of Research in Open and Distance Learning. 2019;**20**(3)

[10] Borg S, Al-Busaidi S. Teachers' beliefs and practices regarding learner autonomy. ELT Journal. 2012;**66**(3):283-292

[11] Knowles MS. Self-directed Learning: A Guide for Learners and Teachers. New York: Association Press; 1975

[12] Gil-Doménech D, Berbegal-Mirabent J. Stimulating students' engagement in mathematics courses in non-STEM academic programmes: A game-based learning. Innovations in Education and Teaching International. 2019;**56**(1):57-65

[13] Cornell University. Center for Teaching Innovation. Collaborative Learning. 2021. Available from: https://teaching.cornell.edu/teaching-resources/engaging-students/collaborative-learning [Last accessed: June 6, 2021]

[14] Uz-Bilgin C, Thompson M, Anteneh M. Exploring how role and background influence through analysis of spatial dialogue in collaborative problem-solving games. Journal of Science Education and Technology. 2020;**29**:813-826

[15] Polytechnic University of Madrid. IEA 6: Componentes de la innovación educativa. El símil de la silla" (in Spanish). 2013

[16] Naik N. The use of GBL to teach mathematics in higher education. Innovations in Education and Teaching International. 2017;**54**:238-246. DOI: 10.1080/14703297.2015.1108857

[17] Takeuchi H. The new dynamism of the knowledge-creating company. Knowledge Economy. 2006;**1**:1-10

[18] Sesen BA, Tarhan L. Active-learning versus teacher-centered instruction for learning acids and bases. Research in Science & Technological Education. 2011;**29**:205-226

[19] Saleh A, Yuxin C, Hmelo-Silver CE, Glazewski KD, Mott BW, Lester JC. Coordinating scaffolds for collaborative inquiry in a game-based learning environment. Journal of Research in Science Teaching. 2020;**57**:1490-1518. DOI: 10.1002/tea.21656

[20] Oseni Z, Than HH, Kolakowska E, Chalmers L, Hanboonkunupakarn B, McGready R. Video-based feedback as a method for training rural healthcare workers to manage medical emergencies: A pilot study. BMC Medical Education. 2017;**17**:1-11

[21] Reher V, Rehbein G, Reher P. Integrating video recording and self-reflection to enhance communication skills training for dental students. IFMBE Proceedings. 2020;**69**:715-719

[22] Young PW. Student-produced video of role-plays on topics in cell biology and biochemistry: A novel undergraduate group work exercise. Frontiers in Education. 2020;**5**:115. DOI: 10.3389/feduc.2020.00115

[23] Donkin R, Askew E, Stevenson H. Video feedback and e-Learning enhances laboratory skills and engagement in medical laboratory science students. BMC Medical Education. 2019;**19**(310):1-12. DOI: 10.1186/s12909-019-1745-1

[24] Fabila AM, Minami H, Izquierdo MJ. La Escala de Likert en la evaluación docente: acercamiento a sus caracterísiticas y principios metodológicos. Textos y Contextos. 2013;**50**:31-40

[25] European Comission. European Credit Transfer and Accumulation System. 2021

[26] European Association for Quality Assurance in Higher Education –enqa. 2021. Available from: https://www.enqa.eu/about-enqa/ [Last accessed: October 4, 2021]

[27] Spanish Ministry of Science, Innovation and Universities. Registry of University Centres and Qualifications. 2019

[28] Rubio-Hurtado M, Berlanga-Silvente V. Cómo aplicar las pruebas paramétricas bivariadas t de Student y ANOVA en SPSS. Caso práctico. REIRE, 5, n° 2. 2012. 10.1344/reire2012.5.2527 (in Spanish)