A Novel Approach to Team-Based Learning Activities in STEM Education

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Abstract

The use of team-based learning activities in STEM education has been reported as a factor to increase the academic performance of learners. However, teamwork might not always be carried out by all members within a team, as some of the members might skip it, thus forcing the rest of the team members to work harder to complete the activity. In order to avoid those situations, a novel approach has been proposed in order for all team members to take part in team activities, which consists of presenting graphical evidence of real teamwork. Such evidence involve either group pictures for in-person meetings or screenshots for online meetings, where timestamps must be provided in both cases. Experimental results with this novel approach displayed a double-figure increase in academic performance in the current year with respect to the outcome obtained in the previous year. Additionally, a t-test was applied to the score distributions obtained in both years, which confirmed that the rise in academic performance was statistically significant. However, the effect size attained was also calculated, which led to a sample size being nearly twice as the actual sample size. Therefore, the actual sample size was insufficient to get the effect size attained, hence further research must be carried out with a larger sample size.

Keywords: active learning, team-based learning, STEM education, descriptive statistics, inferential statistics.

1. Introduction

The role of active learning within the education field has been growing in recent years, mostly since the pandemic lockdown rapidly transformed the landscape related to teaching and learning in all areas and levels of education [1]. Active learning requires some prerequisites in order for students to succeed, such as a good alignment between research and teaching practices, along with a supporting infrastructure related to teaching and learning, and also staff professional development together with appropriate learning designs [2].

Basically, active learning approaches allow students to interact with each other and with the teacher in order to be more engaged, such that discussion gets encouraged, critical thinking gets promoted, and problem solving gets enhanced [3]. Furthermore, incorporating active learning methods with a pedagogical view boosts the outcome obtained [4]. Additionally, many empirical studies in the literature have proved that the use of any of the active learning methods usually results in an improvement of the learning outcomes [5].

Team-based learning furnishes an active and structured scenario for small group learning, which may be applied in classes of any size [6]. It allows to apply conceptual knowledge through a string of activities, which include individual work, team work, and immediate feedback within the context of a small group instructional strategy [7].

The interest in team-based learning has been recently growing, and it has been spread throughout all education areas and levels, although it seems that medical and nursing education are the most prominent areas and higher education is the most prominent level [8]. Also, team-based learning are considered when it comes to stimulating the development of some key transversal skills, such as problem solving, critical thinking, collaboration, leadership, and communication [9]. There are some references in the literature establishing an association between team-based learning with an improvement in academic performance and success rate [10]. Moreover, other references state a positive relationship between the use of team-based learning activities and the success rates achieved by students [11]. Therefore, it appears that the time and effort needed to implement team based learning activities is worth as it results in improving academic results and success rates [12].

In this paper, two different approaches of team-based learning are compared, namely a looser one and a tighter one. Regarding the former, work in teams was expected so as to solve a set of STEM-related problems, even though it was detected that some teams did not solve it on a team basis, as some team members did it on an individual basis. As a consequence, the latter tried to fix this issue by establishing a explicit condition so as to ensure that those sets of problems were solved on a team basis as opposed to carry them out on an individual basis.

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Hence, the research goal in this paper is to try to corroborate the increase in academic performance and success rate when implementing real team-based learning activities within a STEM course in order for students to better consolidate the concepts learned.

The rest of the paper is organized as follows: section 2 describes the method used, section 3 displays the results obtained, section 4 presents the discussion on those results, and finally, section 5 draws the final conclusions.

2. Method

This study was carried out in a college course dedicated to the physical foundations of computer networks, with 50 students registered in the current academic year, namely 2024-2025. Out of those 50 students, 31 were men and 19 were women, whose ages ranged between 18 and 25 years old. Likewise, in the last academic year, the course also had 50 students, with 33 men and 17 women. In both academic years, the course was composed of 5 teaching units, whose target was to introduce the physical foundations under the computer network operations and management.

In this context, last academic year it was decided to implement a team-based learning activity per each teaching unit, such that a collection of 20 physics problems were proposed to be resolved in groups. At the beginning of the course, ten volunteer students were appointed as team leaders of the corresponding teams, and afterwards, four students were randomly assigned to each of these teams. Hence, ten teams were formed, where each one was composed of five students including the team leader. The structure of those teams was the same all along the academic year, such that the components of each group remained immutable for the five team-based activities proposed during the course.

The types of problems to be resolved in each teaching unit were the following: the first one was related to transmission time and throughput, the second one was about modulation and multiplexing, the third one was related to transmission and error control codes, the forth one was about the Aloha protocol and carrier sense multiple access mechanisms, whilst the fifth one was related to Bellman-Ford and Dijkstra algorithms.

The only requirement imposed during last academic year in the team-based learning activities was for a team leader to collect the solved problems and submit them to the teacher through the Learning Management System (LMS) established by the college. However, it was detected that some teams ended up equally distributing the twenty problems assigned in each team-based learning activity into all team components, thus accounting for four problems to each of the five members. Then, each student just solved the amount of problems assigned individually to him/her, and in turn, forwarded the solutions to the team leader in order to get all twenty solved problems packed together and submitted to the teacher. This way, some students did not face all kind of problems proposed, and this fact got reflected in the checkpoint exams for each teaching unit, where some students did not know how to face some specific problems.

In order to avoid this behavior and to force real team activity, this academic year it was required to present graphical evidence of real teamwork while solving the problems. This could be done by presenting pictures of the group solving problems with a timestamp, which applied to either group meetings in-person or online. This way, no matter whether the work was done either in person or online, as long as the problem-solving was carried out on a synchronous basis, meaning that all team members were present during the resolution process. Hence, this approach aims at involving all students in all kind of problems, such that they will know how to face any of them in the checkpoint exams.

In summary, with the system established last academic year, some students did not get in touch with some specific sort of problems proposed, which got them to underperform in the checkpoint exams. Therefore, with the system established this academic year, the goal was to get all students involved in every sort of problems proposed in order to try to improve their performance in the checkpoint exams.

In order to check if this goal was achieved, the grades obtained in the five teaching units in both academic years are confronted regarding academic performance and success rate by means of descriptive and inferential statistics.

3. Results

The following tables display the statistical measures related to the results obtained in the course dedicated to physical foundations of computer networks for the past and the current academic years. It is to be noted that the Spanish grading system ranges from 0 to 10, where 5 is considered as the passing mark [13].

Table 1. Average marks per teaching unit

	Past year	Current year	Increment
Teaching Unit 1 (TU 1)	6.48	7.04	+08.64%
Teaching Unit 2 (TU 2)	6.02	6.60	+09.63%
Teaching Unit 3 (TU 3)	6.08	6.70	+10.20%
Teaching Unit 4 (TU 4)	6.44	7.16	+11.18%
Teaching Unit 5 (TU 5)	6.06	7.32	+20.79%

Specifically, Tables 1 to 4 are dedicated to descriptive statistics, such that Tables 1 to 3 apply centralization statistics, whereas Table 4 applies dispersion statistics. Furthermore, Table 5 works with the Cronbach's Alpha, which is not a statistical test, but it is actually a coefficient of reliability or

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consistency. On the other hand, Tables 6 and 7 are dedicated to inferential statistics.

To start with, Table 1 shows the average marks obtained by all the students in the checkpoint exams, considering each teaching unit within both academic years, along with the increments experienced.

The overall mark for each student is calculated by taking the average scores obtained in all teaching units. This way, the overall mark for the whole course is obtained by calculating the average marks among all students, which is labeled as the academic performance. Table 2 exhibits the academic performance registered in both academic years, along with the increments experienced.

Table 2. Academic performance in the whole course

	Past year	Current year	Increment
Academic performance	6.22	6.96	+12.03%

Additionally, the success rate is calculated as the number of students who got an overall mark equal or greater than the passing mark, which is 5 out of 10. Table 3 displays the success rate registered in both academic years, along with the increments experienced.

Table 3. Success rate in the whole course

	Past year	Current year	Increment
Success rate	37/50 = +74%	42/50 = +84%	+5/50 = +10%

Table 4 exhibits the dispersion statistics related to the distribution of marks in both years.

Table 4. Dispersion statistics for the overall marks

	Past year	Current year	Increment
Variance	3.41	3.28	-3.73%
Standard deviation	1.85	1.81	-1.88%
Coefficient of variation	0.297	0.260	-12.42%

Table 5 shows the reliability and internal consistency of the marks obtained in each academic year by means of the Cronbach's Alpha, which is also related to the correlation degree between the corresponding sets of marks.

Table 5. Internal consistency of the marks per year

	Past year	Current year	Increment
Cronbach's Alpha	0.828	0.860	+3.85%

On the other hand, Table 6 presents the relevant measures needed to apply the t-test to the distributions of the marks obtained in both years.

Table 6. Relevant measures before applying t-test

	N	Mean	Standard deviation
Past academic year	50	6.22	1.85
Current academic year	50	6.96	1.81

Table 7 shows the calculations to find out if the differences between the distribution of marks in both years are statistically significant by means of the two-sided t-test, also known as significance test.

Table 7. T-test applied to both distribution of marks

t-student	2.045
degrees of freedom (df)	50+50-2 = 98
p-value	0.043
s-value	0.05
Interpretation of the p-value	significant

Table 8 depicts the effect size attained in the form of Cohen's d.

Table 8. Effect size attained

Difference of means	0.74
Pooled standard deviation	1.83
Cohen's d	0.40
Interpretation of Cohen's d	small to medium

Eventually, Table 9 exhibits the sample size required in order to get the effect size attained.

Table 9. Sample size required to get the effect size attained

Alpha value (type-I error threshold)	0.05
Beta value (type-II error threshold)	0.20
Effect size attained	0.40
Sample size required	97
Actual sample size	50
Interpretation of sample size	insufficient

4. Discussion

The main point in this paper is to compare the influence of team-based learning activities into the academic performance and the success rate in a STEM college course devoted to physical foundations of computer networks. This is done by comparing the results obtained in the past academic year with those in the current academic year, based on the statistics calculated in the previous tables [14].

Table 1 shows the average marks per teaching unit, where there are increments in all five cases. In fact, the increment rate keeps growing as the teaching units go by, reaching a steep rise in the last one. Specifically, the increase is about 10% in the first four teaching units and about 20% in the last one. This fact

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indicates that the new system had a positive impact in the academic performance by clarifying concepts to the course attendants, especially in the last teaching unit of the course. Moreover, the growing tendency line related to the increases obtained in each checkpoint exam indicates that learners got more and more involved with the new team-based learning activities as the course went by, which is a sign that the new system had a positive impact in students' performance.

Table 2 exhibits the academic performance in the whole course, thus considering the plain average of the five teaching units composing the course. There is an increment of around 12% in the current year with respect to the previous year, which reinforces the fact that the new system had a positive impact in the overall academic performance.

Table 3 displays the success rate obtained at the end of the course, where an increment of 10% has been experienced. This fact reveals that the implementation of the new system implied a fairly high rise in the students being fit enough to pass the course, which strengthens the idea that the new system got the students more prepared.

Table 4 exhibits the dispersion of the results obtained with respect to the mean point. Specifically, variance and standard deviation got reduced nearly 4% and 2%, respectively, whereas the coefficient of variation got shrunk around 12,50%, namely one eighth. These facts reflect that the distribution of marks got closer to the mean value in the current year. Hence, considering that the mean results have been risen as stated in Table 2, it can be said that a great proportion of the students got better marks due to the implementation of the new system. Furthermore, both coefficients of variation were located under 0.30, which is taken as the limit for moderate variability of the data considered. This way, it can be stated that the distribution of results obtained were moderately close to the mean in both academic years, although those attained in the current year were slightly closer to the mean compared to those achieved in the previous year.

Table 5 shows the outcome of the Cronbach's Alpha, which accounts for the reliability and internal consistency of the marks obtained. The values obtained in both years ranged between 0.8 and 0.9, which implies good internal consistency and reliability, along with a high correlation degree among the marks obtained in both years. Furthermore, there has been an increase of around 4%, thus the new system provided more internal consistency regarding the marks attained in the current year.

Table 6 displays the relevant statistics for the distribution of the marks in both years in order to apply the t-test for inferential statistics purposes. In this context, the distribution of the marks obtained in each year is considered as a sample. This way, the measurements shown therein are all referred to a given sample, such as its number of items, its mean and its standard deviation.

Table 7 shows the application of a two-sided t-test to the distribution of the marks in both years. It is to be noted that, regardless of the type of hypothesis proposed, the process to undertake a significance test is always the same, such that it just contains four basic steps. The first step is to state the null and alternative hypotheses, the second step is to collect and summarize the data, the third step is to use the test statistic to find out the p-value, and the fourth step is to interpret the p-value [15].

Generally speaking, the null hypothesis usually states that two samples belong to the same population, whereas the alternative hypothesis usually states that two samples belong to different populations. Hence, focusing on the data studied in this paper, the null hypothesis corresponds to the case where the distributions of marks referred to both years belong to the same population, meaning that there is not a significant change in the marks due to the new system put in place. Otherwise, the alternative hypothesis corresponds to the case where the distribution of marks related to both years belong the different populations, meaning that there is indeed a significant difference in the marks because of the new system established.

With respect to the collection and summarization of data, it has already been contemplated in the previous Tables from 1 to 5, whereas the relevant data to apply a student's t-test have been displayed in Table 6. It is to be reminded that a t-test is a statistical test used to find out if the difference between the responses of two samples or groups is statistically significant, or otherwise.

At that point, the way to obtain the p-value is to calculate the t-student value out of the two samples involved by considering their number of items, their means, and their standard deviations. After that, the p-value is taken out of the t-distribution regarding the t-student value, the degrees of freedom and the number of tails considered.

It is to be noted that the degrees of freedom are taken as the addition of the number of samples minus one item per sample. Moreover, it has been considered a two-tailed test, such that the critical area of the t-distribution is two-sided, thus it is tested if the estimated value goes higher or lower than a certain range of values. This is more appropriate in order to determine if there is a statistically significant difference between the groups involved. In other words, the two-tailed test searches for a change in a given parameter, no matter if this is an increase or a decrease, whereas the one-tailed test searches for either an increase or a decrease in a given parameter.

Once the p-value is obtained, it is compared with the s-value, also known as alpha value, and if the p-value is lower than the s-value, then we would reject the null hypothesis and we would accept the

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alternative hypothesis. Otherwise, we would fail to reject the null hypothesis, so we would not accept the alternative hypothesis.

In this case, as the p-value is lower than the s-value taken, then we may interpret the p-value as significant, thus meaning that the outcome obtained could happen too frequently, such that we can be confident that the new system had an effect on academic performance. In other words, the chances that the outcome obtained happened by chance can be neglected, as the result obtained is statistically significant.

In summary, a t-test has been performed involving the distribution of the final marks from both academic years. This way, if the p-value reported is less than 0.05, then it can be said that the result obtained is statistically significant. Otherwise, if the p-value is greater than 0.05, then it can be said that the result obtained is statistically insignificant. Focusing on the data studied in this paper, as a significant result has been obtained in the t-test, then it implies that the two samples compared belonged to different populations, because the difference in marks between both academic years was significant in statistical terms.

Therefore, as the result of the t-test with the distribution of marks in both years was statistically significant, then it was revealed that there has been a significant improvement in the overall marks in the year where the new method for team-based learning activities was implemented.

Table 8 displays the steps in order to calculate the effect size attained. In this sense, the difference of means can be found out by subtracting the mean values in absolute value shown in Table 6, which happens to be 0.74. On the other hand, the pooled standard deviation can be considered as a statistical measure combining the variances from multiple independent samples. However, in this case there are only two samples, hence it can be seen as a weighted average of the standard deviations of each of the samples involved, thus more weight is assigned to larger samples. Moreover, as both samples used in this case have the same number of items, then the calculation of the pooled standard deviation gets simplified to the squared sum of all individual standard deviations, divided by the number of samples, and applying the square root to the result. Hence, the pooled standard deviation yields 1.83.

At this point, the Cohen's d can be calculated as the quotient of the difference of means divided by the pooled standard deviation. The outcome of this division is 0.40, which is labeled as the Cohen's d, that being considered as the effect size. Focusing of the effect size, it is taken as a quantitative measure related to the magnitude of a phenomenon. Such a measurement indicates the practical significance of a finding, thus indicating how meaningful that finding is. This way, the effect size measures the practical importance of a result, which usually indicates its real-world implications. Also, it allows to compare findings across studies carried out with different sample sizes or different methodologies.

The effect size usually expresses the difference between two or more group means in standard deviation units, which is the case of the Cohen's d. However, other measurements could also be used in order to establish the effect size. This is the case of risk estimates, which are widely used in medicine so as to compare the chances of an event happening to a given group as opposed to another one. Some typical examples of risk estimates are odds ratio and relative risk. Besides, correlation coefficients can be used as well in order to calculate the effect size. This is the case of Pearson's correlation coefficient, which accounts for the strength and direction related to the linear association between a pair of variables, and the Spearman's rank correlation coefficient, which stands for the strength and direction related to the monotonic association between a couple of variables.

Sticking to the case of measuring the effect size in terms of standardized mean differences, as it happens with the Cohen's d, the results are usually interpreted in terms of small, medium, and large. With respect to the benchmarks typically used for each of those terms, a common benchmark of 0.20 is used to account for small effect size, whereas a typical benchmark of 0.50 is established to stand for medium effect size, whilst a usual benchmark of 0.80 is linked to large effect size. Hence, if the value of a Cohen's d goes around any of those values, it is usually labeled with its corresponding term, whereas intermediate values are usually labeled with both their boundary intervals involved. Other less common benchmarks are 0.01 for a very small effect, 1.20 for a very large one, or 2.00 for a huge one.

Regarding the interpretations of the usual benchmarks, a small effect is considered as a difference which is barely perceptible to the naked eye. On the other hand, a medium effect is considered as a difference which is large enough to be noticed by a careful observer at a naked eye, whereas a large effect is considered as a difference which is grossly perceptible, so it is easily seen. Therefore, the smaller the effect, the tougher will be to detect it, thus it would be necessary to have a large enough sample size in order to get it. Otherwise, the larger the effect, the easier will be to detect it, thus it would be possible to get it with a relatively small sample size. Hence, the effect size will be directly related to the sample size required to detect it, along with the maximum rates allowed for type-I and type-II errors, such that all four variables get interleaved.

With respect to the value of the Cohen's d obtained in this study, namely 0.40, this value is around the middle of the interval bounded by the benchmarks related to small effect, namely 0.20, and medium effect, namely 0.50. Therefore, the effect size obtained may well be considered as small to medium

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effect size.

Table 9 exhibits the values involved in the calculation of the sample size required to get the effect size attained. In this sense, the alpha value is 0.05, which accounts for the Type-I error threshold, the beta value stands for 0.20, which accounts for the Type-II error threshold, and the effect size attained is 0.40, as it has been stated above. With those values, the sample size required yields 97, which is nearly twice the actual sample size, namely 50, that being the sample size in both academic years being assessed. Therefore, the actual sample size is clearly lower than the sample size required to get the effect size attained, thus it can be concluded that the actual sample size is insufficient to get the effect size attained during this study. As a consequence, further research needs to be undertaken with a larger sample size in order to meet the desired statistical constraints.

5. Conclusions

In this paper, a study about an enhancement of a team-based learning activity in a college course on physical foundations of computer networks has been exposed. Last academic year, such an activity was proposed where each team had a coordinator or team leader who was in charge to distribute a set of problems among the member of the team, and eventually, collect their solutions and submit them though an LMS to the teachers. However, we suspected that some students did not get fully involved, so in the present academic year, we improved the system by asking for evidence that all members actively participated in the activity.

In order to make sure that the new system accounted for better outcome regarding academic performance and success rate, we undertook a statistical treatment of the results obtained in this course regarding the current and past academic year.

With respect to the average marks per teaching unit, there was a growth in the increasing rate along the course. In this sense, the four first teaching units experienced a rise of around 10%, whilst the fifth one experienced a rise of around 20%, where this last steep rise was due to its inherent difficulty which was partly overcome due to the new system. As a consequence, the average academic performance during the course experienced a rise of around 12%, along with a rise in the success rate of 10%.

Furthermore, the dispersion statistics were reduced, which meant that a bigger proportion of marks were located around the central point of the distribution of marks, while less marks were located far away from that point. Moreover, the coefficients of variation got under 0.30, which accounted for the boundary of the region of moderate variability. Additionally, the reliability and internal consistency of the data obtained were calculated by the Cronbach's Alpha, whose results were increased with the new system, although both sets of marks fell under the interval range of good reliability.

Moreover, the t-test was applied to the distributions of the marks obtained in both academic years in order to check whether the differences in marks were significant or otherwise. The p-value obtained got under the significant value, which was set to 0.05, hence it could be concluded that the difference in marks was statistically significative. Therefore, the implementation of the new system led to a statistically significant improvement in the results obtained during this academic year compared to those obtained during the past one.

Besides, the effect size was found out by means of calculating the Cohen's d. The value attained was 0.40, which is considered as a small to medium effect. Actually, this value is around the middle of the interval between 0.20 and 0.50, where the lower bound stands for an effect barely perceptible with the naked eye and the upper bound accounts for an effect large enough to be noticed by a careful observer with the naked eye.

The effect size was used to calculate the sample size required to attain it, which led to a value of 97. However, the actual sample size was 50, hence the actual sample size was nearly twice the sample size required. Therefore, the actual sample size was insufficient to get the effect size attained. Consequently, further research needs to be carried out with a large sample size in order to meet the desired statistical constraints.

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