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Team-Based Learning in Electrical Engineering Classes

Alana de O. Ferro[1,*], Márcilio B. Fontes [1], Denisia de V. Mota[1], Vanessa S. de C. Texeira[1], Adson B. Moreira[1]

[1]Federal University of Ceará – CE, Brazil.

e-mail: alanaoliveira@alu.ufc.br*; marciliofontes46@gmail.com; engdenisiamota@gmail.com; vanessasct@ufc.br; adsonbmoreira@gmail.com.
*Corresponding author

ABSTRACT The Electrical Machines course requires dedication from students, which is essential for their professional qualification because several economic sectors such as industrial and commercial use electrical machines to drive loads. Aiming the training process of engineering students to encompass the development of technical skills, cognitive skills, and methodological skills, the National Curricular Guidelines (DCN) for Engineering courses in Brazil were revised and published to stimulate institutions to adopt active learning methods. This article presents the results of the Team-Based Learning application in the Electrical Machines Classes. In this research, the strategy was used to improve the learning of the students and develop collaborative work skills. From the analysis of the students' grades obtained in the academic exams from 2010 to 2022 in the Electrical Machine Course of the Federal University of Ceará - Campus Sobral, the topics of Direct Current Machines, Three-phase Transformers, and Synchronous Machines were selected for applying the methodology in 2023. The result is the improvement and leveling of grades in the 2023 semesters.

KEYWORDS electric machines, direct current machines, three-phase transformer, synchronous machine, active learning, teamwork

I. INTRODUCTION

The Electrical Engineering course at Federal University of Ceará (UFC) — Campus Sobral has a semester-based curricular structure, requiring a minimum of 3676 training hours to obtain the Electrical Engineer degree. The curricular components are organized into six nuclei: basic, professionalizing, specific, professional practice, complementary, and extension [1].

The Electrical Machine (EM) course is mandatory, coming from the professionalizing nuclei, its prerequisites are Electromechanical Energy Conversion and Power Electronics, both disciplines from the sixth semester that use the traditional teaching methodology. The course program comprises Three-phase Transformers, Introduction to Alternating Current (AC), and Direct Current (DC) Machines. The course EM requires dedication from the student to understand it, and it is important for his professional qualification because several economic sectors such as industrial and commercial use electrical machines to drive loads. Fig. 1 shows the students' Partial Evaluations Average (PE) graph from 2010 to 2022.2. From 2010 to 2012 the EM course was offered in the annual modality. From the 2017 year, this course became offered as a semester modality.

In the semesters of 2020.1 to 2021.2, the form of teaching and evaluation continued to be traditional with Distance Learning (DL), due to the COVID-19 pandemic. Fig. 1 shows a significant improvement in grades in 2020.1. Still, in the other semesters of the pandemic, there was a worsening in all the course contents, especially in 2021.1. These results show the learning deficiency of students in the traditional format combined with DL.

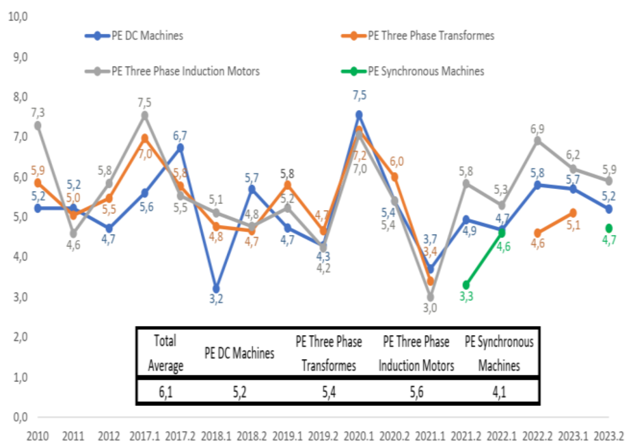

FIGURE 1. Average of Partial Evaluations.

In general, the student grades in the EM course vary from 3.2 to 7.5 on a scale of 0 to 10 - Fig. 1. The student performance in the content of DC Machines averages from 3.2 to 6.7, having increased to 7.5 in the pandemic, the content presents an arithmetic average of 5.2.

In Three-Phase Transformers it averaged 4.6 to 7.5 and obtained an average grade of 5.4. Synchronous Machine averages 3.3 and 4,6 with an average grade of 4.1 being the content with the lowest average. In Three-phase Induction Motors it averages between 4.2 and 7.5 and presents an average grade of 5.6.

The training process of engineering students must encompass the development of a set of skills, such as technical skills, cognitive skills related to the way of thinking, and methodological skills that involve the ability to apply knowledge in practice and use new technologies [2].

The curricular structure often limits students to pre-determined paths, which makes learning and developing permitted professional skills difficult. In April 2019, the National Curricular Guidelines (DCN) for Engineering courses in Brazil were revised and published to stimulate institutions to adopt active teaching methods focused on developing essential skills of future engineers [3].

The term Active Learning began to be used by Reginald William Revans in 1940 [4]. The distinctive feature of Active Learning is having the student as the protagonist of a learning process that, in addition to technical and cognitive development, provides opportunities to apply knowledge in practical situations. Its principles include student-centered learning, autonomy, reflection, addressing real-world problems, teamwork, innovation, and the role of the teacher as a facilitator [5].

The Team-Based Learning - TBL method was developed by management and business professor Larry Michaelsen [6]. As indicated by TAN, *et al* [7] and NYINDO, *et al* [8], the TBL methodology fosters greater collaboration among students and between students and teachers. Improves knowledge scores in undergraduate neurology education, with sustained and continuing improvement. This effect is greater in low-performance students. Students taught by TBL report high engagement which may promote greater self-directed learning [7]. The study results demonstrate a high degree of student acceptance of TBL. In addition, between 2011 and 2012, the frequency distribution of student final examination grades dramatically changed, with much higher scores for the lower half of both students [8].

The method was chosen because it provides a constant search for knowledge, independence, and responsibility, improves learning, and the developing collaborative work skills [9] which are characteristics required for the Electrical Engineer in the job market. It is important to clarify that this methodology can be implemented in other subjects of Electrical Engineering like Power Electronics.

The main objective of this article is to present the results of an Active Learning Methodology applied in the EM Classes to increase the results of the content of DC Machines, Three-phase Transformer, and Synchronous Machines. The results obtained in the fourth section of this article demonstrate that this work contributed in a more relevant way to the learning of students with a lower level of performance.

The leveling occurs through the teamwork that the methodology proposes helping students develop critical thinking and the ability to argue and defend their opinions about the study content.

II. BIBLIOGRAPHIC REFERENCES

A. *TEAM-BASED LEARNING METHODOLOGY*

Focusing on improving learning and developing collaborative work skills, through a structure that involves the management of learning teams, preparation tasks and application of concepts, constant feedback, and evaluation between colleagues that can be implemented in the disciplines of the Electrical Engineering course [6].

The implementation of TBL needs lesson planning based on TBL stages and the importance of individual student preparation. Lack of preparation undermines team performance, requiring the teacher to ensure the students' adequate preparation, possibly through assessments that confirm the student's initial reflection [6].

The main motivation is to make students feel responsible for their learning and that of their teammates. By promoting conceptual and procedural knowledge that will be applied to solving problems that the student will face in their professional life. Fig. 2 shows the Fundamental Elements of the TBL Method essential for its application: Teams - must be composed of students with different characteristics, Accountability - students must be responsible for the quality of their work and the group's work, Feedback - students must receive an opinion or immediate feedback and Task Design - tasks must promote group learning and development [6].

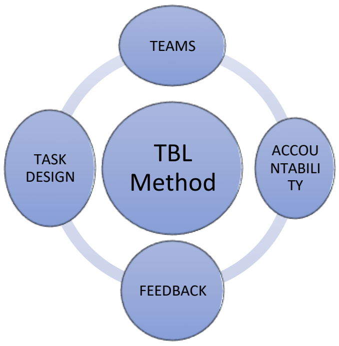

FIGURE 2. Fundamental Elements of TBL Method.

Fig. 3 shows the Stages of the TBL learning process. Stage 1 – Prior Preparation which consists of pre-class study, where the student prepares for the activity through content in the ME discipline. Stage 2 – Preparation Assurance is the phase in which students must answer questions related to the content studied in the individual test (Individual Readiness Assurance Test – iRAT), the same questions must be answered by the group in the team test (Team Readiness Assurance Test – tRAT) where the answer must be discussed, analyzed and given unanimously to all members of the group, after these two steps the answer key is released in real-time [6].

In Stage 3 – Appeal, students may disagree with the answer if they find the formulation of the question ambiguous and/or subject to cancellation, and Stage 4 – Application of Concepts is the phase that will consist of solving problems as a team that is significant and require the practical application of the concepts discussed in the second stage, which may be open or multiple-choice questions that must be answered by the group through the presentation of results or the correction of questions with the chance for discussion and reasoned argumentation [6].

FIGURE 3. Stages of TBL Learning Process.

To verify the students' achieved performance and analyze whether there was a real improvement, this work will use the results from the iRATs, tRATs, and the problems of the fourth stage [19]. Additionally, the efficiency of the process will be evaluated to identify possible causes of failure in learning. This will be achieved through self-assessment and team assessment.

III. METHODOLOGY

A. *RESEARCH PARTICIPANTS*

The present research took place at the UFC – Campus Sobral, involving undergraduate students in Electrical Engineering enrolled in the EM discipline. The content covered included DC Machines, Three-Phase Transformers, and Synchronous Machines. The study was conducted in 2023, with a workload of 6 hours/class per week, involving 26 students in the 2023.1 semester and 22 students in the 2023.2 semester.

B. *PROCEDURES PERFORMED*

Table I shows the TBL stages schedule. Each step of the activity was explained in detail for ten minutes during the test application. Steps 2 to 4 were conducted simultaneously, with clarification on the scoring for the individual test, the group test, and the application of concepts.

TABLE 1. TBL Stages Schedule.

STAGE	
Stage 1 – Prior	– Start of content presentations through classes and provision of slides in the institutional system; – Notice to students to prepare for the TBL test.
Stage 2 – Preparation Assurance	– Assessment of learning in the Electrical Machines discipline through the application of TBL; – Explanation of the score for the individual test, the group test, and the application of concepts; – Explanation of how to fill out the answer sheet: with 8 questions with 4 alternatives each (iRAT and tRAT);
Stage 3 – Appeal	– Explanation of how to appeal;
Stage 4 – Application of Concepts	– An explanation of the fourth stage, with 6 groups of 3 to 5 students and a draw for the 6 questions.
Self-Assessment and Team Assessment	– Performed later after the TBL using an electronic form on the Google Forms platform.

Stage 2 – Preparation Guarantee, students received printed questions and an answer card to write their names and mark their answers, as illustrated in Fig. 4. Initially, the individual test (Individual Readiness Assurance Test – iRAT) was conducted with a stipulated time of 20 minutes.

Fig. 5 shows the 6 teams that were formed heterogeneously, following the criteria of the minimum and maximum number of students per group. The groups in the test team (Team Readiness Assurance Test – tRAT), had a stipulated time of 20 minutes to answer the questions, this time unanimously the 4 points should be placed on the alternative that everyone considered correct. The official answer sheet was then made available on the board.

FIGURE 4. Stage 2 Application - Individual Readiness Assurance Test.

FIGURE 5. Stage 2 Application - Team Readiness Assurance Test.

Stage 3 – Appeal, students were given 5 minutes to appeal any answer they considered incorrect in the answer sheet. After this time, there would be no further appeal.

Stage 4 – Application of Concepts (AC), with 30 minutes for resolution. The draw was important for fair allocation without giving one team privileges over the others. Then, a member of each team was called to answer the question on the board and receive immediate feedback on correct answers, corrections, and scores of the question. Fig. 6 – shows the resolution of the questions by the students.

The self-assessment and team assessment were performed to analyze the difficulties of each participant and to evaluate their preparation, participation, and contribution as well as that of their teammates. It was also asked whether the test experience was positive.

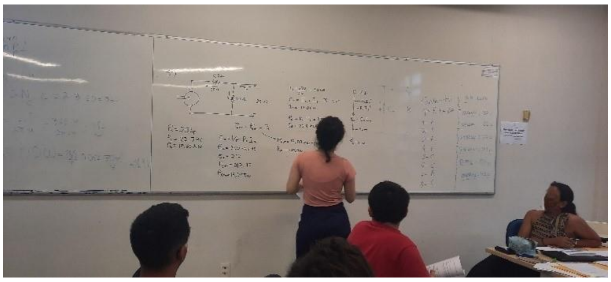

FIGURE 6. Stage 4 - Application of Concepts.

To outline the quantitative results, the results of the iRAT, tRAT, and the fourth stage were used, based on the calculation of the Probability Density Function (PDF) to obtain the grade dispersion and the skewness coefficient to determine whether the grades are concentrated above or below the arithmetic mean [9-13]. The TBL activity has a total value of 4 points (40%) of the PE Final grades, distributed as follows: 2 points for iRAT, 1 point for tRAT, and 1 point for AC. And 6 points (60%) of the PE Final grades, for the traditional testing method.

IV. RESULTS AND DISCUSSIONS

A. *RESULTS AND DISCUSSIONS OF THE METHODOLOGY IMPLEMENTATION*

The methodology was adopted in the semesters of 2023 and is currently ongoing. In the semester of 2023.1, the contents of DC Machines and Three Phase Transformers were evaluated with TBL. In the semester of 2023.2, the subject of Synchronous Machines replaced the content of Three Phase Transformers Fig. 7 to 10 and Tables 2 and 3.

In Fig.7 and Table 2 according to the normal distribution curve, the average score for the total TBL in DC Machines is 3.2, representing 80% of the activity points. This value coincides with the most frequent score in the activity, indicating satisfactory efficiency. Furthermore, the skewness coefficient of -0.1862 suggests that most students achieved grades above the average.

TABLE 2. Estimate of grades of Semester 2023.2.

		Rates	Estimate (%)			Rates	Estimate (%)
DC Machine	TBL	2.2 – 2.5	7.69	Three Phase Transformer	TBL	1.5 – 1.9	40.00
		2.5 – 2.9	15.38			1.9 – 2.3	8.00
		2.9 – 3.2	7.69			2.3 – 2.7	12.00
		3.2 – 3.5	34.62			2.7 – 3.1	24.00
		3.5 – 3.7	11.54			3.1 – 3.5	16.00
		3.7 – 4.0	23.07				
	PE	0.0 – 1.2	7,69		PE	0.0 – 1.2	12.00
		1.2 – 2.0	38,46			1.2 – 2.4	16.00
		2.0 – 3.0	11,54			2.4 – 3.6	44.00
		3.0 – 4.1	15,38			3.6 – 4.8	16.00
		4.1 – 6.0	15,38			4.8 – 6.0	12.00
		6.0	11,54				
	PE - Final	2.0 – 3.0	7,69		PE - Final	2.0 – 3.3	12.00
		3.0 – 4.5	19,24			3.3 – 4.6	24.00
		4.5 – 6.0	23,07			4.6 – 5.9	24.00
		6.0 – 7.1	23,07			5.9 – 7.2	24.00
		7.1 – 8.0	15,38			7.2 – 8.5	16.00
		8.0 – 9.1	11,54				

* skewness coefficient DC Machine: TBL = -0.1862; PE= 0.1766; and PE-Final =-0.0683

** skewness coefficient Three Phase Transformer: TBL = 0.1412; PE=-0.3886 ; and PE-Final =0.3205

Comparing the PE DC Machines normalized average with the previous semesters shown in Fig. 1, we observed that it falls within the range of the collected averages. Thus, the class performed similarly to its predecessors in this form of evaluation. Since 30.77% of students achieved grades at the peak of the Gaussian curve, and with a skewness of 0.1766, it can be concluded that most students' grades are below the average.

The PE Final in DC Machines average is 5.9, demonstrating that the inclusion of this methodology was important for the increase of 2.9 points (49.2%) in grades for the semester 2023.1. As indicated by the skewness coefficient of -0.0683 the students' achieved grades are at the base of the Gaussian peak, which shows the grades are more distributed above the average.

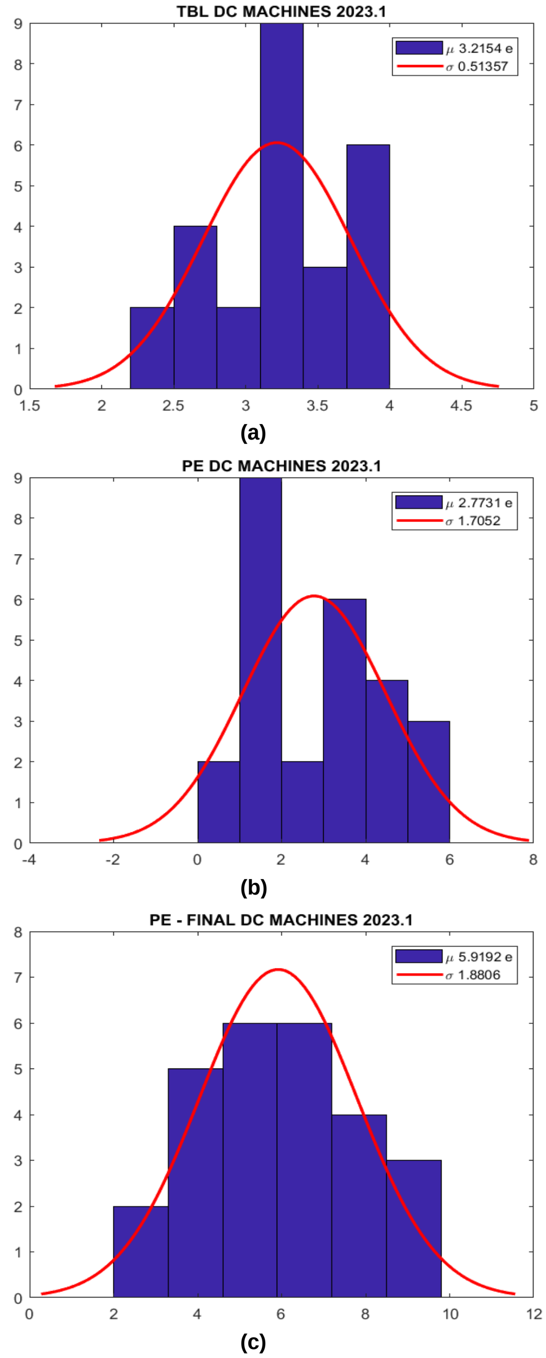

FIGURE 7. Frequency Histogram and Gaussian Distribution 2023.1 a) TBL DC Machines, b) PE DC Machines, c). PE – Final DC Machines.

In Fig.8 and Table 2, the average total TBL in Three-Phase Transformers is 2.4, which comprises 60% of the activity points. And 53.84% of students achieved grades at the peak of the Gaussian curve. However, the skewness of 0.1412 indicates that most grades are below the average.

The average for PE Three-Phase Transformers normalized is similar to the previous grades, and 46.15% of the students achieved grades at the peak of the Gaussian curve and the skewness of -0.3886 indicates the grades are above the average.In Three-Phase Transformers, according to the normal distribution curve, the average PE - Final is 5.4, demonstrating that the inclusion of this methodology was important for the increase of 2.4 points (44.77%) in grades for the semester 2023.1 and 57.69% of the students achieved grades at the peak of the Gaussian curve. This shows that students' grades are more level in the content of Three-Phase Transformers compared to administering the test on DC Machines.

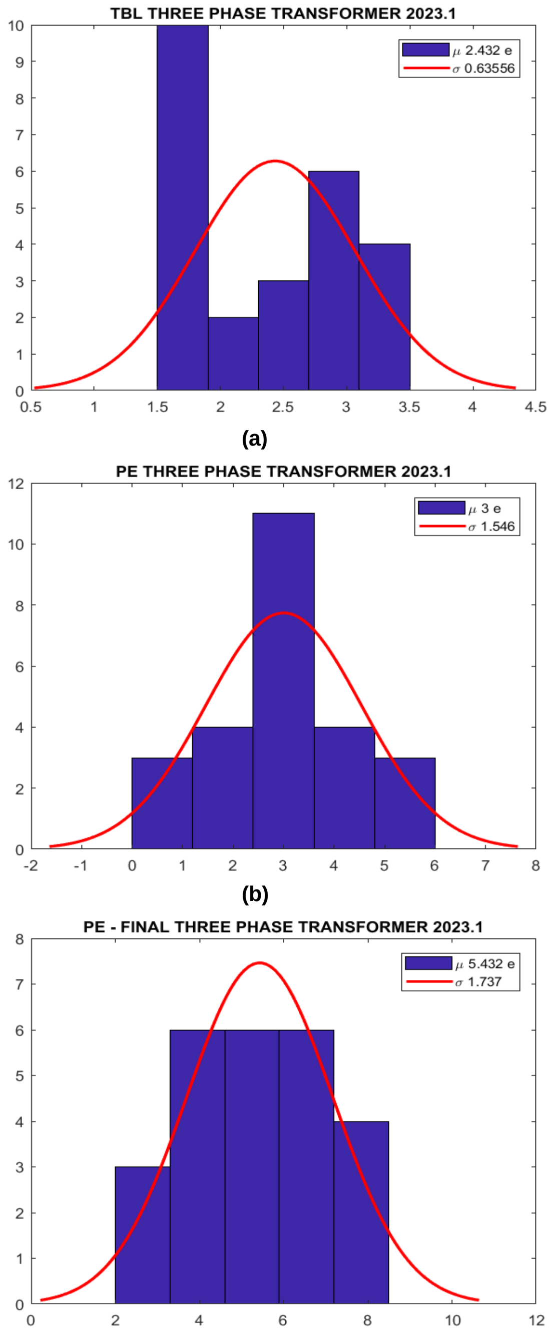

FIGURE 8. Frequency Histogram and Gaussian Distribution 2023.1 a) TBL, b) PE Three Phase Transformer, c). PE – Final Three Phase Transformer.

In Fig.9 and Table 3, according to the normal distribution curve, the average total TBL in DC Machines 2023.2 is approximately 2.4, which comprises 60% of the activity points and coincides with the most frequent value in the activity and grades more concentrated in the average, but the skewness coefficient of 0.8225 indicates that most grades are below the average.

The average for PE DC Machines 2023.2 normalized is similar to the previous grades, and 47.62% of the students achieved grades at the peak of the Gaussian curve, and the skewness of 0.1459 indicates the grades are below the average.

The PE Final in DC Machines average is 5.4, demonstrating that the inclusion of this methodology was important for the increase of 2.4 points (44.4%) in grades for the semester 2023.2. As indicated by the skewness coefficient of 0.0671 the students' achieved grades are in the base of the Gaussian peak, which shows the grades are more distributed in the average.

TABLE 3. Estimate of grades of Semester 2023.2.

		Rates	Estimate (%)			Rates	Estimate (%)
DC Machine	TBL	2.0 - 2.2	19.05	Synchronous Machine	TBL	1.9 - 2.1	14.29
DC Machine	TBL	2.2 - 2.4	23.80	Synchronous Machine	TBL	2.1 - 2.2	19.05
DC Machine	TBL	2.4 - 2.6	42.86	Synchronous Machine	TBL	2.2 - 2.4	23.80
DC Machine	TBL	2.6 - 2.8	0.00	Synchronous Machine	TBL	2.4 - 2.5	19.05
DC Machine	TBL	2.8 - 3.0	14.29	Synchronous Machine	TBL	2.5 - 2.7	28.57
DC Machine	PE	0.0 - 1.2	14.29	Synchronous Machine	PE	0.0 - 1.3	33.33
DC Machine	PE	1.2 - 2.4	23.80	Synchronous Machine	PE	1.3 - 2.5	28.57
DC Machine	PE	2.4 - 3.6	28.57	Synchronous Machine	PE	2.5 - 3.8	28.57
DC Machine	PE	3.6 - 4.8	14.29	Synchronous Machine	PE	3.8 - 5.0	9.52
DC Machine	PE	4.8 - 6.0	19.05	Synchronous Machine	PE	5.0 - 6.2	4.76
DC Machine	PE - Final	2.0 - 3.3	14.29	Synchronous Machine	PE - Final	2.7 - 3.9	28.57
DC Machine	PE - Final	3.3 - 4.6	28.57	Synchronous Machine	PE - Final	3.9 - 5.1	33.33
DC Machine	PE - Final	4.6 - 5.8	14.29	Synchronous Machine	PE - Final	5.1 - 6.4	33.33
DC Machine	PE - Final	5.8 - 7.1	23.80	Synchronous Machine	PE - Final	6.4 - 7.6	4.76
DC Machine	PE - Final	7.1 - 8.4	19.05	Synchronous Machine	PE - Final	7.6 - 8.8	4.76

* skewness coefficient DC Machine: TBL = 0.8225; PE=0.1459 ; and PE-Final =0.0671

** skewness coefficient Synchronous Machine: TBL =-0.1331 ; PE= 0.8609; and PE-Final =1.0503

According to the normal distribution curve, the average total TBL in Synchronous Machines is 2.3, which comprises 57.5% of the activity points, and the skewness coefficient of -0.1331 indicates that most grades are above the average.

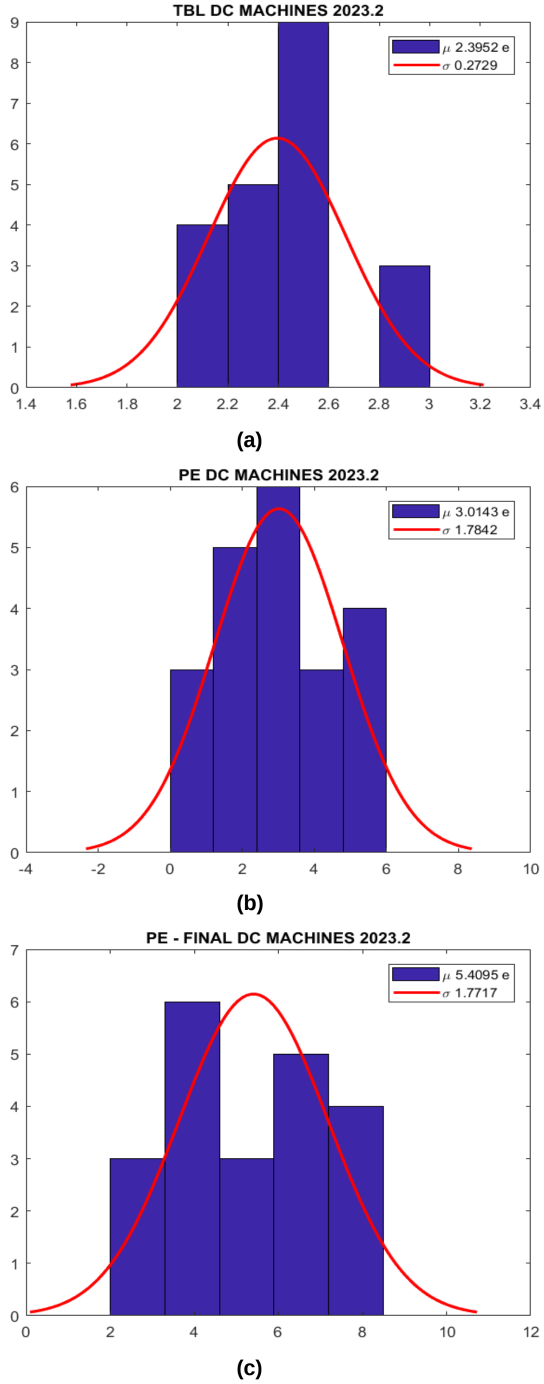

FIGURE 9. Frequency Histogram and Gaussian Distribution 2023.2 a) TBL DC Machines, b) PE DC Machines, c) PE – Final DC Machines.

The average for PE Synchronous Machines normalized is similar to the previous grades with the previous semesters shown in Fig. 1, and 40.91% of the students achieved grades at the peak of the Gaussian curve, and the skewness of 0.8609 indicates the grades are below the average. In Synchronous Machines, the average PE – Final is 4.6, demonstrating that the inclusion of the methodology was important for the increase of 2.3 points (50%) in the grades of the semester 2023.2, but the skewness of 1.0503 indicates the grades are below the average. Considering that grades in the PE ranged from 0 to 6, in the PE – Final they did not have values below 2 points, demonstrating that the method was important so that low-performing students did not have a score equal to 0.

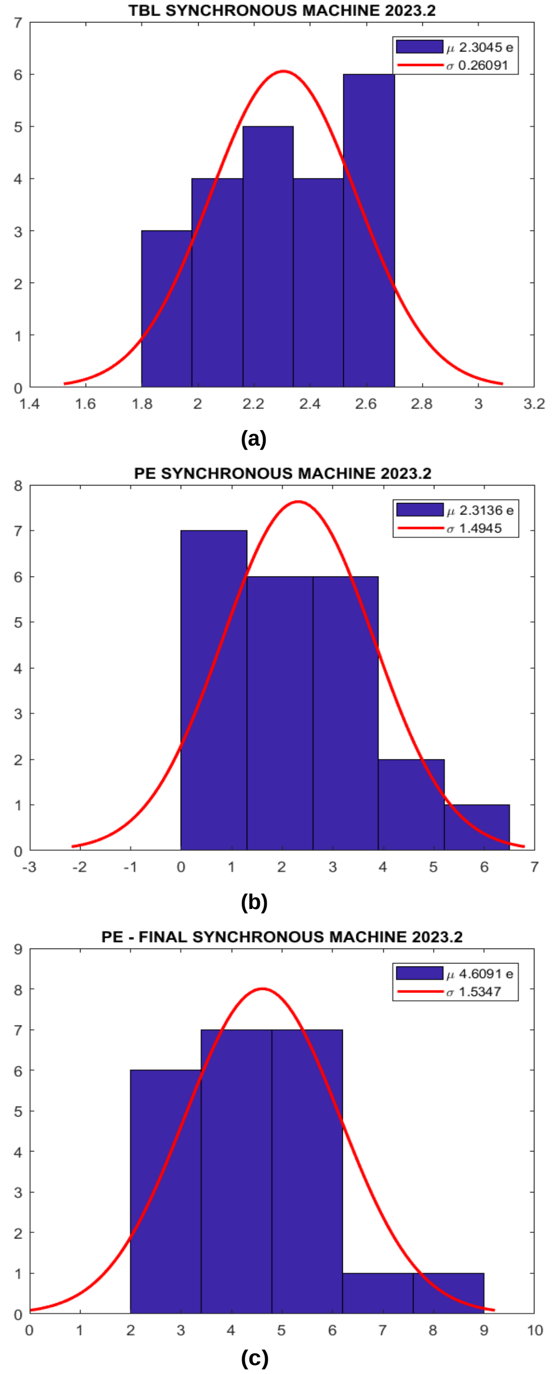

FIGURE 10. Frequency Histogram and Gaussian Distribution 2023.2 a) TBL Synchronous Machines, b) PE Synchronous Machines, c) PE – Final Synchronous Machines.

Comparing these results with those from the 2022.1 and 2022.2 semesters (Fig. 11), it is evident that the traditional method produced differences in grades across the subjects DC Machines, Three-Phase Transformers, and Synchronous Machines. The skewness coefficients for these subjects were 0.0218, -0.1881, and 0.0686, respectively. These values indicate that grades in DC Machines were below the average, grades in Transformers were above the average, and grades in Synchronous Machines were close to the average.

When the TBL methodology was applied alongside the traditional method in 2023.1 and 2023.2, students achieved more consistent and higher grades across all subjects.

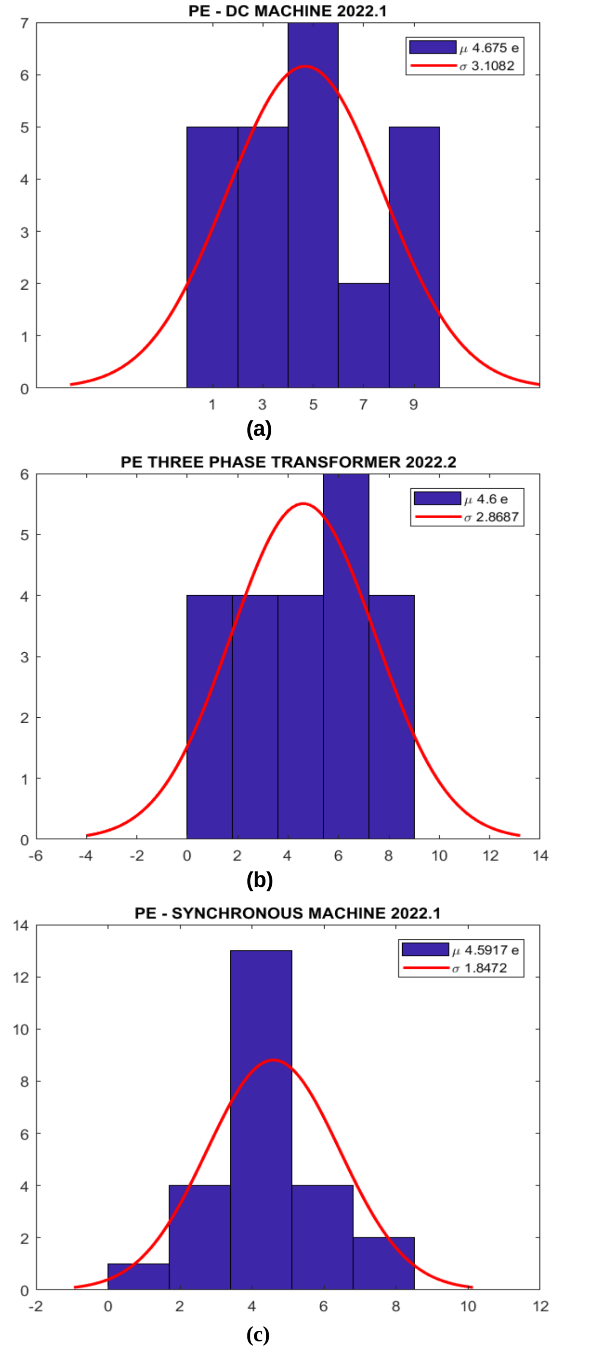

FIGURE 11. Frequency Histogram and Gaussian Distribution a) PE DC Machine 2022.1, b) PE Three Phase Transformer 2022.2, c) PE Synchronous Machine 2022.1.

This proves that the introduction of the TBL learning method was beneficial for improving the grades of students who had very low grades and for the class to have more equal grades.

B. *SELF-ASSESSMENT AND TEAM ASSESSMENT RESULTS*

It was obtained 21 responses to the self-assessment and team assessment form, representing an 80.77% response rate. Fig. 12 shows the question assessed the student's level of difficulty in understanding the content of the EM classes, where (14.3%) said they had much difficulty and (85.7%) said they had little, some, or no difficulty with the subject.

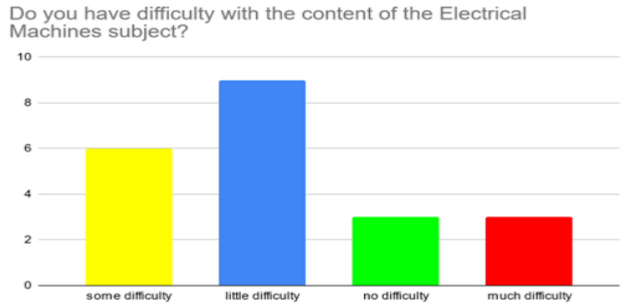

FIGURE 12. Question about difficulties in the contents of EM.

Fig. 13, shows the questions were made to find out the level of individual preparation, participation, and contribution. For each student's self-assessment on individual preparation, (19.1%) had bad or reasonable preparation and (80.9%) had good, great, or excellent preparation. In terms of individual participation and individual contribution (14.3%) had a reasonable level and (85.7%) had a good, great, or excellent level. These results highlight that participation and contribution levels were higher than preparation levels.

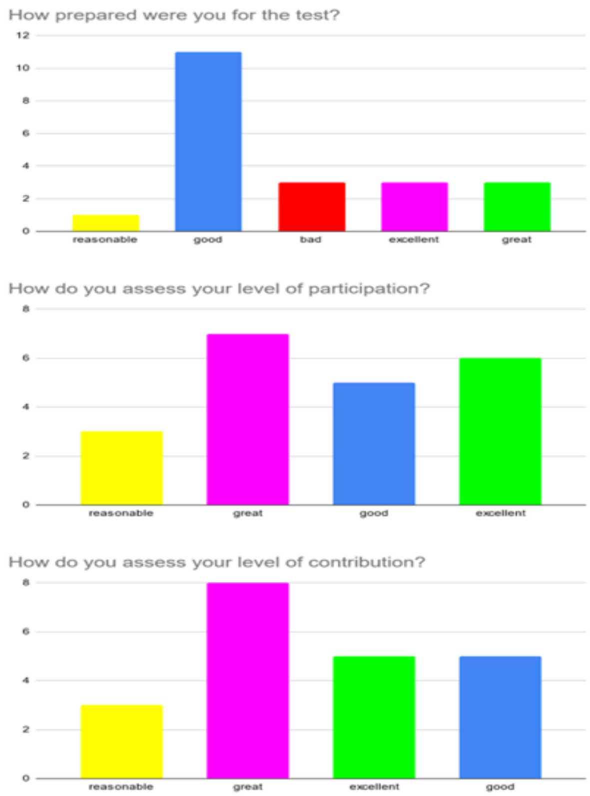

FIGURE 13. Questions about individual preparation, participation, and contribution.

Fig. 14, shows the questions that were asked to find out the level of preparation, participation, and contribution of the team. For the evaluation of preparation and participation in the team (9.5%) attributed a reasonable level to their team and (90.5%) attributed a good, great, or excellent level. And in terms of contribution (14.3%) attributed a reasonable contribution from their team and (85.7%) attributed a good, great, or excellent contribution. Showing that students assessed that their teammates were more prepared and participative, but with a lower contribution percentage.

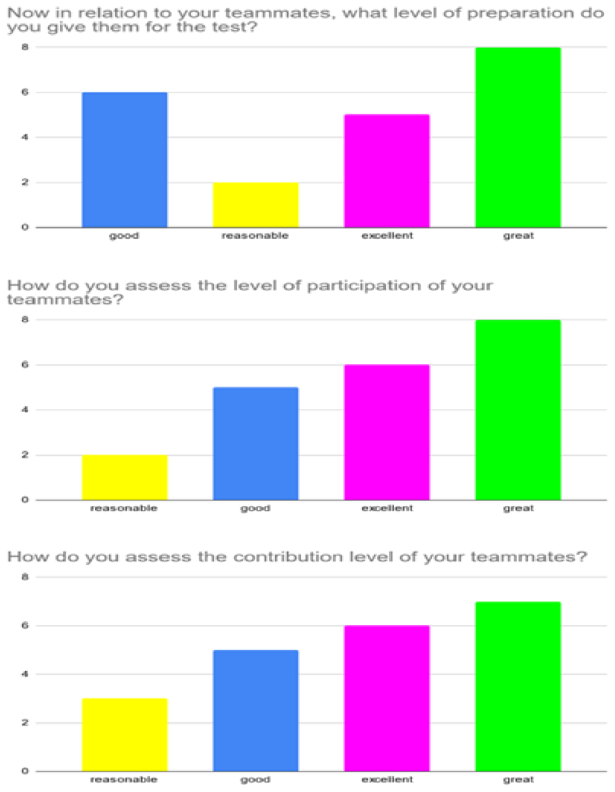

FIGURE 14. Questions about team preparation, participation, and contribution.

Fig. 15, shows the question to analyze the learning method. Which, all students (100%) find the experience positive and would like to be assessed again using this method.

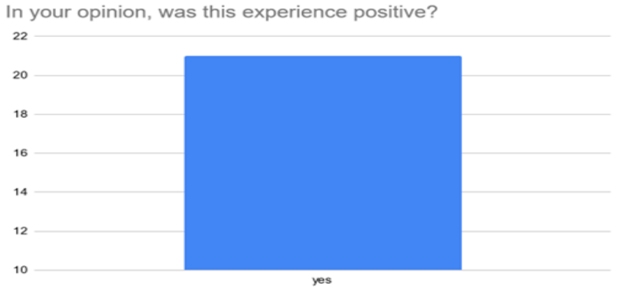

FIGURE 15. Question about student perception of the methodology.

V. CONCLUSION

It is concluded that the results of applying the TBL method in the discipline of DC Machines, Three-Phase Transformers, and Synchronous Machines, in the EM classes of the Electrical Engineering course at the UFC – Campus Sobral, were efficient, as there was an increase of 49.15 %, 44.4% and 50% respective in grades. The results obtained include improvements in the grades of lower-performing students, thereby leveling the performance of the entire class.

However, in Three-Phase Transformers the desired leveling was not achieved because the inclusion of the method increased the standard deviation. The performance of the class decreased when the active method was applied. It was constant in the traditional method, which may indicate a failure in one of the steps. Another factor that may have contributed to the lower performance in this content may be the repetitiveness of the application.

Nevertheless, contrary to the grades of previous semesters that had many low and high grades the leveling occurred because the methodology helped in understanding the content through collaboration and teamwork. Due to the ease of application and acceptable results, this method has applicability in other subjects of the Electrical Engineering course. In turn, it will continue to be applied in ME classes in 2024 to analyze student grades in subsequent semesters.

In the 2024.1 semester, the number of questions was changed to 20, the answer key contains the alternatives of true or false in the iRAT and tRAT, the application time in the iRAT is 25 min and in the fourth stage AC the time is 25 min. The effect of changes in the time and style of questions on students' performance will be analyzed.

AUTHOR'S CONTRIBUTIONS

A. O. FERRO: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – Original Draft, Writing – Review & Editing. **M. B. FONTES**: Formal Analysis, Software, Validation, Visualization, Writing – Review & Editing.
D. V. MOTA: Data Curation, Formal Analysis, Software, Validation, Visualization. **V. S. C. TEXEIRA**: Conceptualization, Formal Analysis, Funding Acquisition, Investigation, Methodology, Resources, Supervision, Validation, Visualization. **A. B. MOREIRA**: Conceptualization, Funding Acquisition, Methodology, Resources, Supervision, Validation, Visualization.

PLAGIARISM POLICY

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BIOGRAPHIES

Alana de Oliveira Ferro Graduated in Electrical Engineering (2024) from the Federal University of Ceará (UFC), Sobral Campus. She served as a teaching assistant for the courses in Electromechanical Energy Conversion and Electric Machines (2022). Currently, she is a student in the Graduate Program in Electrical and Computer Engineering (PPGEEC) at UFC, with a research focus on power electronics, specifically in the area of energy efficiency in drive systems. Her areas of interest include energy efficiency, electric machines, and IoT.

Márcilio Barros Fontes Graduated in Electrical Engineering (2024) from the Federal University of Ceará (UFC), Sobral Campus. He served as a teaching assistant for the courses in Electromechanical Energy Conversion and Electric Machines (2023). Currently, he is a student in the Graduate Program in Electrical and Computer Engineering (PPGEEC) at UFC, with a research focus on power electronics, specifically in energy efficiency in drive systems.

Denisia de Vasconcelos Mota Graduated in Electrical Engineering (2021) from the Federal University of Ceará (UFC), with a master’s degree in electrical and computer engineering also from UFC, and currently pursuing a specialization in Electrical Projects and Renewable Energies. She was a researcher from 2018 to 2020 with the Ceará Foundation for Scientific and Technological Development Support (FUNCAP) and from 2021 to 2023. Additionally, she conducted research under the National Council for Scientific and Technological Development (CNPq). She has teaching experience in Higher Education in the subject of Electrical Machines. Her areas of interest include power generation, renewable energies, energy efficiency, power quality, and artificial intelligence.

Vanessa Siqueira de Castro Teixeira Holds a degree in Electrical Engineering (2004) and a Master's degree in Power Electronics and Drives of Electrical Machines (2008) from the Federal University of Ceará. She obtained a PhD in Electrical Engineering from the State University of Campinas (UNICAMP) in 2018. She is currently an Associate Professor of the Electrical Engineering Course at the Federal University of Ceará – Sobral Campus. He has experience in the area of Electrical Engineering, working mainly on the following topics: Design of Electrical Machines, Variable Reluctance Electrical Machines, Electrical Machine Modeling Techniques and Energy Efficiency in Driving Systems. Is a member the Brazilian Society of Automation (SBA) and the Brazilian Association of Engineering Education (ABENGE).

Adson Bezerra Moreira Holds a bachelor's degree (2003) and a master's degree in Electrical Engineering (2006) from the Federal University of Ceará (UFC). From 2007 to 2008 he served as a substitute professor in the Department of Engineering Electrical of UFC / Fortaleza-CE. From 2008 to the present, he has been working as an effective professor of the Electrical Engineering course at UFC / Campus de Sobral-CE. During the period from 2010 to 2012 he served as coordinator of the Electrical Engineering course, and as tutor of the Tutorial Education Program (PET/UFC) from 2010-2012 and 2020-2022. He obtained the title in 2017 PhD in Electrical Engineering from the State University of Campinas (UNICAMP). As of 2018, he becomes a permanent professor of the Program Graduate Program in Electrical and Computer Engineering (PPGEEC/UFC/Sobral-CE). From 2018 to 2020 he worked as a Research Productivity Fellow at the Ceará Foundation for Support to Scientific and Technological Development (FUNCAP). He has experience in area of Electrical Engineering, working mainly on the following topics: energy efficiency, electrical machines, power electronics, electric machine drives, active power filter and alternative sources of electric energy (wind generation, solar generation), quality of energy.