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The Impact of the Conceptual Mind Facts Methodology on the Academic Performance of Engineering Students*

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This study explored the impact of an innovative learning methodology, Conceptual Mind Facts (CMFs), on the academic performance of mechanical engineering and industrial engineering students at the Universidad del Norte, Barranquilla, Colombia. This approach was applied in the theoretical component of the Materials Science module undertaken by these students. The reason for selecting this subject was due to the high percentage of students (greater than 80%) failing this course in recent years. Failure was particularly likely among students with a cumulative grade point average (GPA) less than 3.24 points (so-called type III students). The sample comprised 992 students (414 in the control group and 578 in the experimental group) during three study periods. A quantitative quasi-experimental research design was used, including three measurements composed of the scores achieved by students on the three assessments of the Materials Science module. Statistical analysis showed that CMFs helped students develop the skills needed to improve their performance in the theoretical component of the module, which lead to a decrease in the number of students failing the course. Importantly, CMFs were also revealed to increase the number of type III students passing the module. Therefore, it was evident that the use of this pedagogical tool had a positive impact on the academic performance of students.

Keywords: Conceptual Mind Facts; *Mentefacto Conceptual*; academic performance; learning strategy; instruments of knowledge

1. Introduction

With the passage of time various dimensions that make up the human being have evolved, one of them being education and more specifically the processes of learning and teaching-student interaction. Learning is understood as a dynamic process and not a copy of reality that is limited to the reproduction of behaviors and stimuli presented, in which the subject and the object of learning exist independently, and with the student studying the object impartially. Therefore, it is considered as a process of contextualized and subjective reconstruction, where there is prior knowledge that influences new content and students are aware of how learning is received and they thus self-regulate the process [1].

Knowledge has certain particularities of being, defined as practice or "praxis". This implies knowledge to achieve certain purposes, that is, practice is know-how. This way of understanding the generation of knowledge determines the way individuals teach. It has to be where the theory – practice tension lies, typical of the university level, given by the teacher training and its specific purpose of inserting students into a different logic of knowledge [2, 3]. Therefore, addressing theory-practical relationships from didactics is complex because it is not a question of merging or confusing theory and practice, but in recognizing the contribution that each makes to didactic action.

Theory is a set of laws, statements and hypotheses that shape scientific knowledge, systematized and organized. However, it seems that theory has its own way of being transmitted which is rooted in university practices. It is carried out with the modality of teaching focused on knowledge mediated by the teacher with exhibition or narrative classes, where the leading role is held by the teacher and the student is a passive entity that is limited to performing cognitive processes of a lower order such as listening, remembering or understanding, as raised in the taxonomy of Bloom [2–4]. Different from this didactic modality is teaching focused on practice, which encourages the application of concepts and therefore its intention is to introduce students to their "logic" or "way of operating" knowledge. This process requires active ownership of skills by students, in an interaction with teacher-mediated practical knowledge. This didactic form tends to the theory-practical articulation that leads to higher-order cognitive processes such as analyzing, evaluating and providing solutions to real problems [2].

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In this sense, it is necessary to have teaching strategies that allow identification of the preconceptions that students bring regarding the concepts that are intended to be addressed in the classroom and that promote the active role of the student in order to achieve meaningful learning. Therefore, the authors inquired about different pedagogical tools that could help to improve the learning process through reading and understanding and, in turn, facilitate the development of cognitive processes of a higher order. This led to the articulation of the following question. Does the implementation of Conceptual Mind Facts as a pedagogical strategy used in the theoretical component of the Materials Science module improve students' academic performance?

The implementation of Conceptual Mind Facts (CMFs) with respect to engineering students is an innovative option, bearing in mind that this domain of knowledge requires students to transpose theoretical concepts towards practical application. In turn, this will contribute to the acquisition of higher-order skills that involve analysis and evaluation of concepts to provide solutions to engineering problems. A bibliometric study of CMF applications and influence on the development of higher-order cognitive skills in students showed that there are limited studies in this regard; and those that do exist have mostly been applied at the secondary education level. The few cases that were found at the university level were limited to courses in Philosophy, Pedagogy and Social Sciences. No studies were identified that linked CMFs to meaningful learning in Engineering.

In order to address the problem question, the authors carried out research focused on evaluating the effect of CMFs as a teaching strategy in the Materials Science module undertaken by Mechanical and Industrial Engineering students at the Universidad del Norte, Barranquilla, Colombia. This teaching strategy was applied in the theoretical component of the module. This need arises because, historically, a high percentage of students have failed this module. As such there is a critical need to intervene in terms of rethinking the strategies used in class. Fig. 1 shows that although the minimum grade required to pass the module is 3.0 points, over the last 6 years this pass threshold has only been met by students who, as a result of their scores in previous semesters, have a cumulative six-monthly grade point average (GPA) between 3.64 points and 3.92 points, on average 3.77 points.

1.1 Academic Performance as a Measurement Variable

Academic performance is a problem involving students, faculty, and the context surrounding these actors. For the purpose of this research, the definition of academic performance proposed by Caballero, Abello, and Palacio [5] was adjusted. As such, academic performance is understood to involve the fulfillment of established goals, achievements and objectives in the subject and is expressed through qualifications and evaluation results that quantify ability, or lack thereof. Importantly, Lamas [6] states that while the purpose of academic performance is to achieve an educational goal, there are determinants such as competencies, motivation, study habits, among others, that affect the results obtained and can lead to a gap between students' actual and expected academic performance, what the author calls *dissenting performance*. This is an unsatisfactory result that is below the expected performance and can sometimes be related to the teaching methods used.

Enríquez, Fajardo and Garzón [7] state that learning is significant when the student relates the contents in a non-arbitrary and substantial way with previous knowledge. This process takes place when students possess concepts, stable and defined

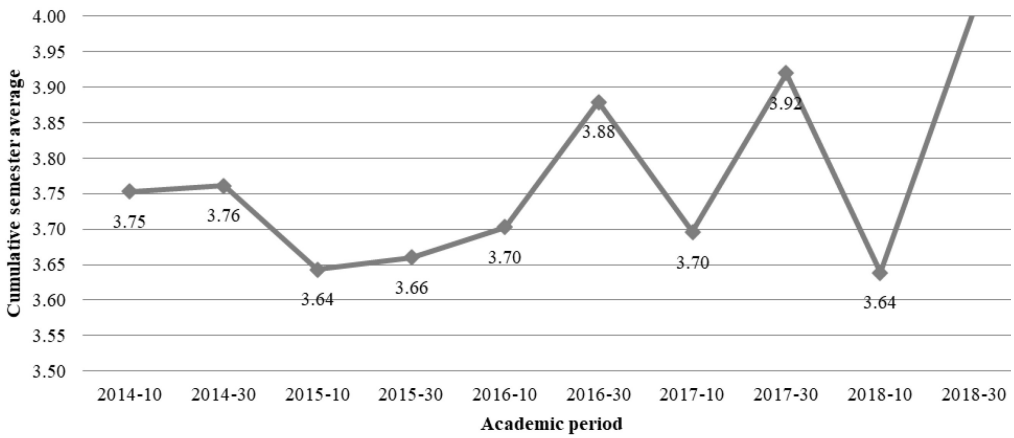

Fig. 1. Minimum GPA required to pass the Materials Science module.

propositions, and ideas in their cognitive structures that can relate to new information. In this sense, the fulfillment of achievements in the subject that is evident in test results, is not isolated from the learning process and the development of students' skills during the course. Instead, the results become proof that the student is learning. For this reason and in order to improve the academic performance of students in the Materials Science module, the implementation of CMFs was proposed as a pedagogical strategy for use in the theoretical component of the module.

1.2 Conceptual Mind Facts as a Teaching and Learning Strategy

Conceptual Mind Facts was developed by a Colombian academic and thus has its origins in the Spanish language. Specifically, the term *Mentefacto Conceptual* was proposed by Miguel de Zubiría [8] in 1998 as a graphical tool to characterize the internal structure of a concept in a simple, efficient and aesthetic way. De Zubiría [8] states that concepts, notions and categories are important to understand learning; he refers to them as *Instruments of Knowledge*. These are mental tools that help to understand the real and symbolic/linguistic environment. CMFs allow for the organization of proposals, the preservation of knowledge and the condensing of large amounts of intellectual information into simple diagrams [9]. For this reason, the author of this tool established four main proposals: *Supraordinate, Isoordinate, Underordinate* and *Exclusions*, organized as shown in Fig. 2 [8]. The supraordinates are the upper class that includes the subject to be studied. The isoordinates group the main characteristics and properties that make up the concept. The underordinates are the subclasses of the concept and, finally, the exclusions are those classes that belong to the same supraordinate but oppose or exclude each other with the main theme [8].

According to the foregoing, this strategy was used in the theoretical component of the focal Materials Science module because, as suggested by De Zubiría [8], CMFs allow to identify if the student is understanding what is and is not part of the concept. This enables recognition of the preconceptions that the student has and gives rise to the analysis of the concept. Parra and Lake Vergara [10] suggest that CMFs are "*extraordinary tools*" that allow the student to save time and valuable intellectual efforts because they provide a way of learning which is superior from the perspective of intuition and recall. It is a tool that facilitates the understanding and interpretation of texts through the concept-proposition relationship - central elements in the structuring of thought that allow the construction of CMFs [11].

From another angle, De la Herrán [12] proposes that it is possible to use CMFs to delimit any concept in any discipline and this can contribute to generating clearer conceptual knowledge. That author states that CMFs (a) are an effective tool that improves the understanding of concepts (b) promote the recall and remembering of concepts and the establishment of relationships with other

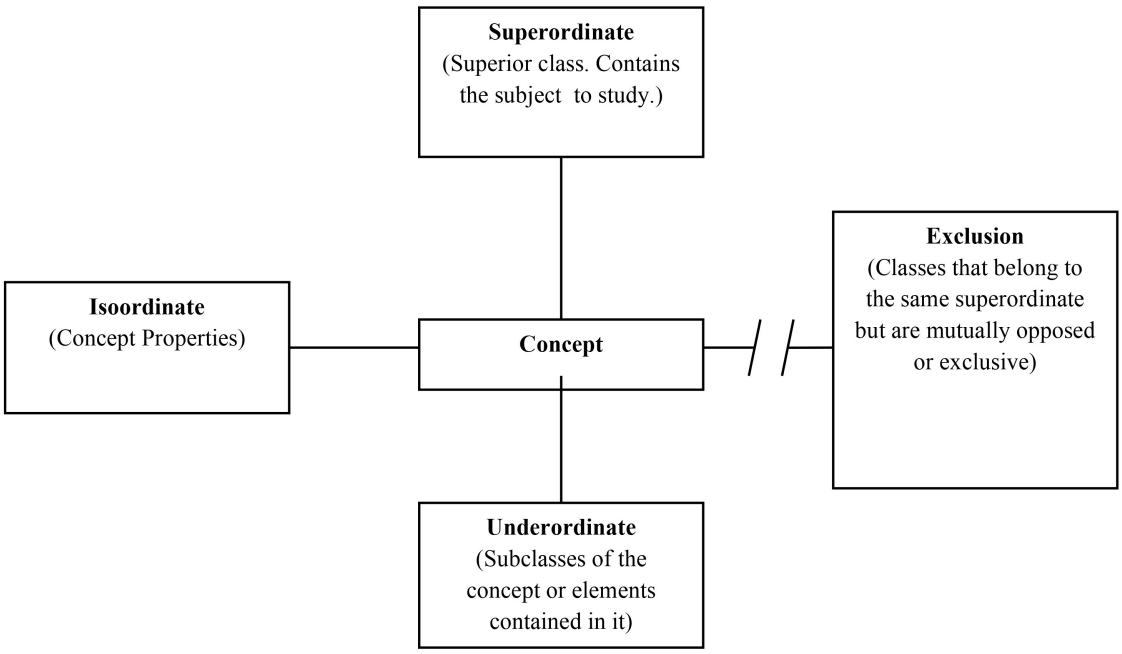

Fig. 2. Conceptual Mind Facts.

concepts of different or equal complexity (c) are useful as a functional guide for teaching the conceptual part of a subject (d) are an evaluation tool and (e) help to detect gaps in approach and explanation. Jama-Zambrano and Cornejo-Zambrano [13] add that this tool helps to protect and preserve newly acquired knowledge by virtue of the two suboperations that the student must undertake to construct the diagram: extract the fundamental ideas of the concept (and to do this they must eliminate secondary or irrelevant ideas) and consequently, graphically recreate the main ideas found, which implies a robust learning process. In addition, this allows for the structuring of instruments of knowledge in the student's long-term memory [14].

The usefulness and importance of CMFs has been validated in various studies such as that carried out by Mendoza and Huarachi [15] on third-year students undertaking a module entitled Contemporary Pedagogical Currents taught at the Universidad Nacional Jorge Basagre Grohmann Those authors aimed to establish the degree of effectiveness of CMFs as a metacognitive strategy to increase the levels of academic achievement. They applied a survey to identify which study strategies students utilize most frequently, then applied an entry test that allowed them to identify the quality of learning acquired prior to the implementation of the CMFs. After that, an exit test was used to assess the levels of learning achieved by students after experimentation. The results showed an improvement in the management of concepts after the implementation of CMFs and a reduction in the dispersion of students' learning levels.

Jama-Zambrano and Cornejo-Zambrano [13] utilized tests, surveys, interviews and observation sheets, in conjunction with primary and secondary sources of information, in order to determine perceptions about the usefulness of CMFs as a strategy to develop meaningful learning in teachers and students. Those authors concluded that the tool facilitates the organization of acquired knowledge and the elaboration of these diagrams allows the student to integrate what they have learned in a more productive way. They also point out that those students who exhibit mastery in the management of CMF benefit from a more effective and coherent learning process than those who did not use the tool. Finally, students expressed that it was easier for them to remember the topics worked on in class when the teacher used CMFs as a teaching-learning strategy.

In an investigation carried out by Garay [16], the use of CMFs as a teaching resource was studied in the context of learning in a social sciences course at the Universidad Alas Peruanas. The sample consisted of 405 students divided into control and experimental groups. The author designed the Questionnaire for Learning (CCSS) to measure five dimensions of learning: i. attitudes and perceptions, ii. acquisition and integration of knowledge, iii. extension and deepening of knowledge, iv. significant use of knowledge and v. mental habits. Overall results showed that CMFs positively influence students' learning processes. Representative differences were found between the control group and the experimental group with respect to four dimensions: (i) extension and deepening of knowledge, (ii) acquisition and integration of knowledge, (iii) significant use of knowledge and (iv) mental habits. The authors concluded that knowledge organizers, such as CMFs, help to highlight key concepts and vocabularies, while establishing relationships between them. This encourages the development of critical and creative thinking in students and maximizes the effects of social learning, which is based on building, reflecting, criticizing, producing, arguing and projecting acquired knowledge. Torres [17] conducted a study on fourth-graders at the Institución Educativa Champagnat in Tacna to measure the effectiveness of CMFs in improving students' learning in Science, Technology and Environment. The research was based on a quasi-experimental design with the use of pre-tests and post-tests. The results indicate that CMFs significantly improve students' learning levels and the teaching strategy demonstrated effectiveness in processing information from fundamental concepts by improving students' learning processes. Ichaps [18] studied the influence of this strategy on the analytical capacity of fourth-graders at Institución Educativa "Santiago of Pichos Tayacaja. A quasi-experimental research design was operationalized with control and experimental groups. The results indicated that use of the pedagogical tool had a positive impact on the analytical abilities of students.

Olortin [19] conducted research on third-graders at the Institución Educativa Inca Huiracocha in Aucayacu-Huánuco, in order to determine the impact of CMFs on reading competencies. He conducted an explanatory study with a quasi-experimental design. The sample comprised 60 students divided into control and experimental groups. CMFs were used in 12 learning sessions and the results showed that the tool was significant in improving reading competencies, making it easier for students to develop the ability to obtain, interpret, reflect and evaluate information from written texts. Along the same line, Quevedo [11] conducted research to examine how the use of CMF and concept maps allow eighth graders to develop historical thinking to make learning history mean-

ingful. The author used a research-action approach with quantitative and qualitative analysis. The results indicated that the application of graphic organizers positively influences the construction of meaningful learning among history students.

Finally, in the area of Engineering, studies reporting the use of CMFs as a learning tool are lacking. However, in a study conducted by Ning [20], a sample of 165 engineering students were assessed and explored in terms of their experience with conceptual mapping, a tool similar to CMFs which, according to the author, is a powerful technique that promotes the organization of knowledge and the ability to configure relationships between concepts, as well as the possibility of discriminating that which does not belong to them. This allows students to understand and analyze the given theory and concepts. The results showed that many students positively perceive the use of conceptual tools because they help them make connections, facilitate understanding of concepts, and help them review what they have learned.

2. Method

The science and engineering of materials is a multidisciplinary subject in which fundamental sciences such as chemistry, physics and mathematics converge. Chemistry is required in the synthesis processes of inorganic and organic materials, as well as for their classification, characterization and evaluation of properties. Through physics it is possible to study the mechanical, optical, electrical and magnetic thermal properties of materials and with the help of mathematics design processes are evaluated, allowing the theoretical study of practical processes with applications in engineering fields (e.g., electronic, electrical, chemical, mechanical, civil, environmental, and industrial). This suggests the need for students' understanding and mastery of a network of fundamental concepts from different areas [21].

At the Universidad del Norte, the Materials Science module is taught in the third semester with a weekly load distributed through 1 hour of laboratory classes and 3 hours of theoretical-practical classes. The assessment of this module is divided into two interim and a final exam, each accounting for 25% of the final grade. Students' performance in laboratory classes and continuous evaluation activities (workshops, games and CMFs) is also assessed, accounting for 25% of the final grade. There are no prerequisites for studying this module and, thus, there is the possibility that it is taken by second semester students. The Materials Science syllabus covers deep and broad content spanning disciplinary terms, measurement systems, and spatial reasoning to understand: 1. What materials are made of, 2. How they are classified from their atomic ordering 3: How they work in terms of their properties, and 4. What your application is. These four criteria should be understood in an interrelated manner as seen in the tetrahedron of materials science (Fig. 3). The study of materials science marks is approached via teaching strategies that help improve the learning process through reading, understanding and analysis, note-taking, underlining main ideas, and CMFs that allow structuring, guiding, comparing and limiting concepts.

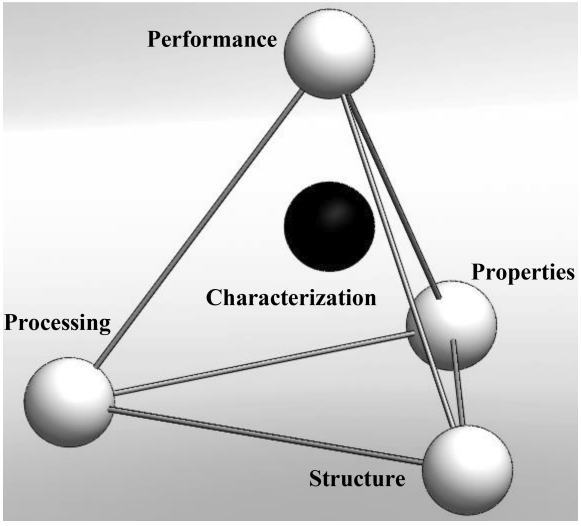

Fig. 3. Materials Science tetrahedron.

Based on the foregoing, and taking into account the performance of students through various study periods, it has been identified that understanding of new terms and their location within a general context, allows students to improve understanding of academic content. In this way, CMFs have been applied with the aim of defining specific concepts, placing them within a macro family, differentiating them from other concepts belonging to that family, describing them through their main characteristics and even classifying them in more detail. Importantly, it is the student who, from their previous knowledge, initially performs the didactic transposition. Therefore, this strategy takes into account the particularities of each student and their previous knowledge, allows to incentivize the role of the student and their interaction, to promote the understanding of new knowledge through an experiential appropriation that promotes apprehension. The methodology applied to implement CMFs is detailed in Fig. 4.

A quasi-experimental quantitative research design was used in order to analyze the effect of implementing CMFs in the context of the theoretical component of the Materials Science module. The effect was analyzed in terms of the academic

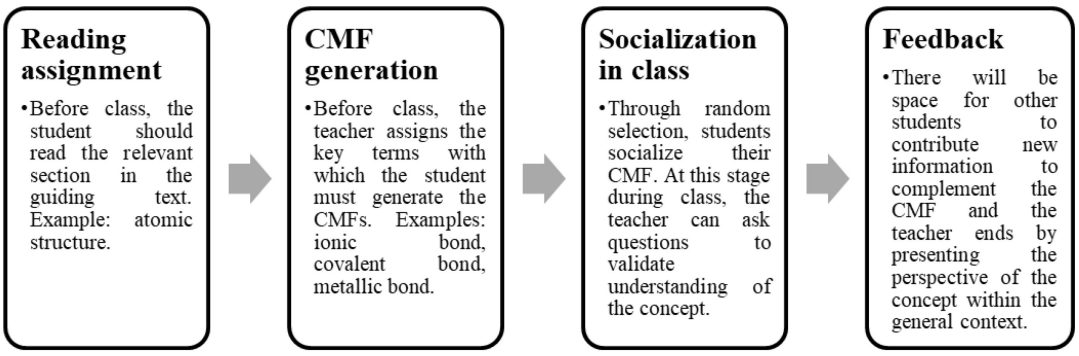

Fig. 4. Methodology for application of Conceptual Mind Facts in the Materials Science module.

performance of students in the three assessments that are completed during the academic period: Assessment I (AI), Assessment II (AII) and Final Assessment (FA). To this end, interpretative questions were asked, to focus the ability of students to discover relationships between definitions and phenomena applied to understand and recognize the fundamentals of material sciences. Thus, the implementation of CMFs focused on the development of higher-order skills, in which it intervenes: (1) Analysis. Ability to distinguish and separate the different parts of a whole until their principles become known, (2) Synthesis. Ability to reach the composition of a whole from the knowledge and gathering of its parts, (3) Conceptualization. To identify the aspects that are necessary and sufficient to describe a phenomenon or problem. (4) Information management. Ability to visualize a set of rules, principles, or measures that are related to each other. [22]

To analyze the results of CMF implementation, the statistical techniques described below were utilized:

- *Kolmogorov-Smirnov Test for a sample:* This is a goodness-of-fit test to assess whether the data meets the normality criterion and proceeds with comparisons in independent samples.
- *Mann-Whitney Test:* This is a nonparametric test applied to two independent samples to compare the median of these samples.
- *Bivariate Bar Charts:* These allow visualization of the behavior of a quantitative variable taking into account categorical variables.
- *Box and Whiskers Diagram:* These make it easy to describe important sample characteristics, such as scattering and symmetry.

For statistical analyses a significance level of 0.05 was considered, i.e. the results of statistical tests are reliable at the 95% level.

2.1 Sample

Nine hundred and ninety-two students of mechanical and industrial engineering at the Universidad del Norte, Barranquilla, Colombia enrolled in the Materials Science module in different periods (from 2017 to 2019) participated. Students were in the second and third semesters of study. Ages ranged between 18 and 21 years. Most of the participants are Colombian nationals. For the analyses, a control group was configured, which was evaluated for two consecutive periods prior to the implementation of the methodology. Three experimental groups were evaluated in three consecutive academic periods (PI, PII and PIII). Table 1 summarizes the sample sizes considered.

Table 1. Sample sizes

Period	Experimental Group	Control Group
PI	146	414
PII	226	
PIII	206	

3. Results

3.1 Student Academic Performance

To study the performance of the students, four analyses were carried out based on the grades obtained in the theoretical component of three assessments in three consecutive academic periods of study. The weighting of theory with respect to the whole of the assessment varies depending on the topics that are evaluated therein; so, for performance analysis, students' results were differentiated in the theoretical and practical components, then a scale conversion of 0.0 points (minimum) to 5.0 points (maximum) of the theory scores was applied according to the scale stipulated in the Uninorte Student Regulations [23] where a student is considered to have passed the test when they obtain a minimum score of 2.96 points The results obtained, on average, in the control and experimental group are shown in Fig. 5. From this, the following can be evidenced:

1. *First assessment:* Students in the control group passed the theoretical component of the assess-

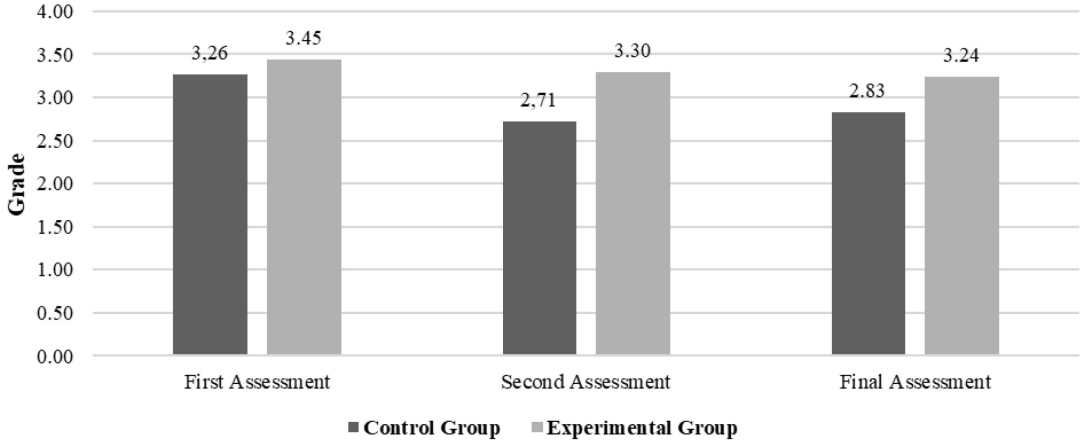

Fig. 5. Average assessment scores on the theoretical component.

ment with an average of 3.26 points. However, there is an increase in academic performance after applying the CMF methodology in the periods of analysis, where students scored on average 3.46 points. Fig. 6a shows that 50% of students in the experimental group scored between 3.00 and 4.00 with a median of 3.33 and a lower limit of 1.67. In contrast students in the control group exhibited lower performance on average with 50% scoring between 2.76 and 3.79, and the lower limit is also below that of the experimental group. The dispersion of the data was similar between both groups, but the variation in the first quartile was slightly lower in the experimental group.

2. *Second assessment:* Prior to the application of CMFs, on average students did not pass the theoretical component of the second assessment, presenting an average of 2.73 points. After the implementation of the methodology, it was observed that, on average, students passed the theoretical component of this assessment with an average of 3.30 points (Fig. 5) Fig. 6b shows better results for the experimental group, where 50% of students scored between 2.50 and 4.00, with a median of 3.50 compared to the control group where 50% of students scored between 1.50 and 3.50, with a median of 3.00. In general, the dispersion of assessment scores is greater in the control group, especially between quartile one and three, and the lower limit was 0.00 in this group, in contrast to the experimental group where the lower limit was 0.50.
3. *Final assessment:* Fig. 5 reveals better performance in the theoretical component of this assessment in the experimental group. The control group obtained, on average, a result of 2.85 points in contrast to the experimental group, which achieved an of 3.23 points. In addition, 50% of the students in the control group achieved results between 2.00 and 3.50, with a median of 3.00, i.e., half of the population failed the final exam. In contrast, in the experimental group, 50% of students achieved grades between 2.50 and 4.00, with a median of 3.50, meaning that there was an increase in the academic performance of students in the experimental group. It is also observed that the upper limit is higher after CMF implementation with some students achieving the maximum grade. The dispersion of the data was similar between quartile one and three (Fig. 6b).

Initially, the Kolmogorov-Smirnov test was applied to determine whether the data meets the normality criterion using the SPSS statistical software package. The results are shown in Table 2. The test was performed under the Null Hypothesis: The data conform to a normal distribution, against the Alternative Hypothesis: The data do not conform to a normal distribution. It was obtained that, with 95% confidence, the data are not normally distributed, so the null hypothesis is rejected, and the comparison is made for independent samples through the Mann-Whitney test for non-parametric samples.

The Mann-Whitney test was applied to compare the median results of each part of the experimental groups with respect to those in the control group. A 95% confidence level was used and under the Null Hypothesis: The medians of the results are statistically equal, against the Alternative Hypothesis: There is a positive statistical difference in the medians of the results. The analysis was performed for each assessment independently.

- *First assessment:* The Mann-Whitney test results for the first assessment show that there is a significant positive difference in the results of

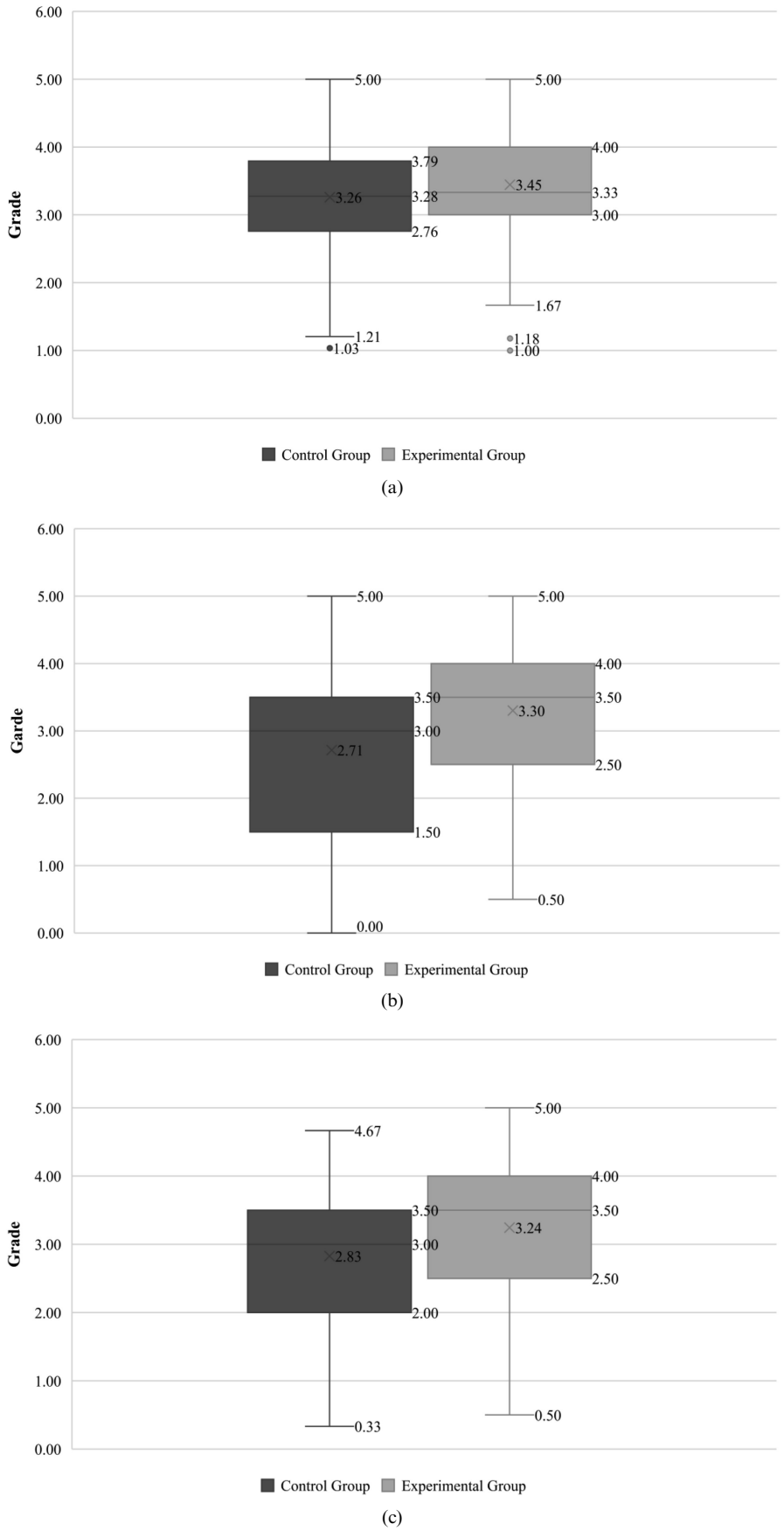

Fig. 6. Results in the theoretical component of the assessments: (a) first assessment, (b) second assessment, (c) final assessment.

Table 2. Kolmogorov-Smirnov test for a sample

Kolmogorov-Smirnov test for a sample				
		First Assessment	**Second Assessment**	**Final Assessment**
N		909	733	678
Normal parameters[a,b]	**Mean**	3,3589	3,0429	3,0894
	Standard deviation	0,69850	1,08114	0,89286
Asymptotic significance (bilateral)		0,000[c]	0,000[c]	0,000[c]

the theoretical component (Table 3). The significance obtained was 0.000 for both groups, so the null hypothesis that proposes equality of medians is rejected.

- *Second assessment:* For the second assessment, the test again shows that there is a significant positive difference in the results of the theoretical component (Table 4). The significance obtained was 0.000 for both groups.
- *Final assessment:* Finally, the Mann-Whitney test showed that there is a significant positive difference in the results of the theoretical component of the final assessment (Table 5). The significance obtained was 0.000 for both groups.

3.2 Module Completion and Academic Status

Two course completion states are stipulated: Passed and Failed. The student is considered to have passed the subject when they obtain a weighted final grade equal to or greater than 2.96 points (which by rounding to one decimal place is equal to 3.0 points); otherwise, failed. Taking into account the foregoing, an analysis of the completion status of the Materials Science module was performed before and after applying the CMF methodology (Fig. 7). For this it was considered that the size of the experimental and control groups during evaluation periods were different, so a representative population sample size was taken from the group with fewer individuals. The equation proposed by Murray and Larry [24] was used with a 95% confidence level, a sample error of 5% and a population standard deviation of 0.5 were used.

It is evident that before the implementation of CMFs to strengthen learning of the theoretical component of the module, less than half of the students passed. Using this learning strategy, we discern a significant increase in the proportion of students who pass the subject, being the minimum obtained of 50% in the second application period. From this it can be concluded that CMFs contribute to improving the academic performance of students.

The Universidad del Norte ranks students according to their cumulative grade point average (GPA), demarcating between type I, II and III students. Type I students are those whose cumulative GPA is between 3.95 points – 5.00 points. Type II students have a GPA in the range of 3.25 points – 3.94 points and Type III students have a GPA equal to or less than 3.24 points. As type III students historically present the highest risk of failing the module, this group was analyzed to evaluate whether the strategy implemented helps to increase their performance.

Table 3. Mann-Whitney test for the first assessment

First assessment				
	N	**Z**	**Average Range**	**Significance (Value P)**
Control Group	488	–4,010	422,60	0.0000
Experimental Group	421	–4,010	492,56	0.0000

Table 4. Mann-Whitney test for the second assessment

Second assessment				
	N	**Z**	**Average Range**	**Significance (Value P)**
Control Group	320	–6,334	311,31	0.0000
Experimental Group	413	–6,334	410,15	0.0000

Table 5. Mann-Whitney test for the final assessment

Final assessment				
	N	**Z**	**Average Range**	**Significance (Value P)**
Control Group	266	–5,146	291,60	0.0000
Experimental Group	412	–5,146	370,42	0.0000

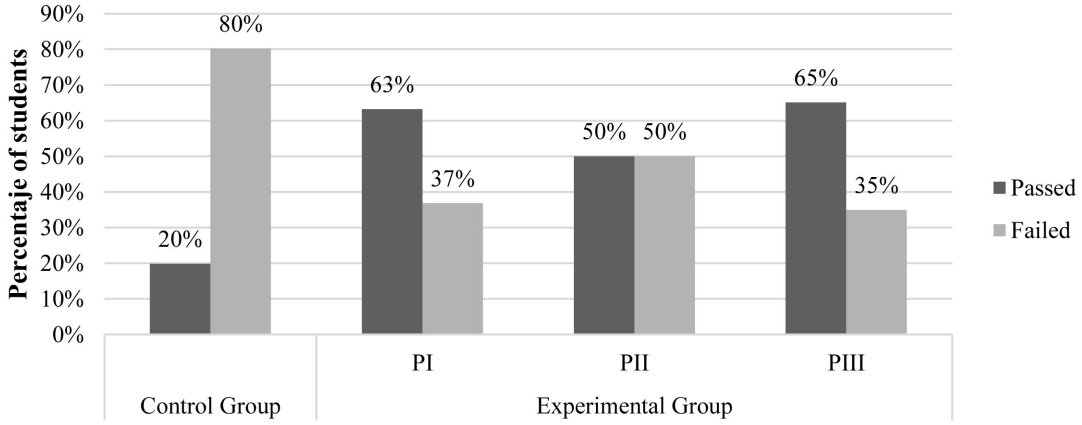

Fig. 7. Module completion status.

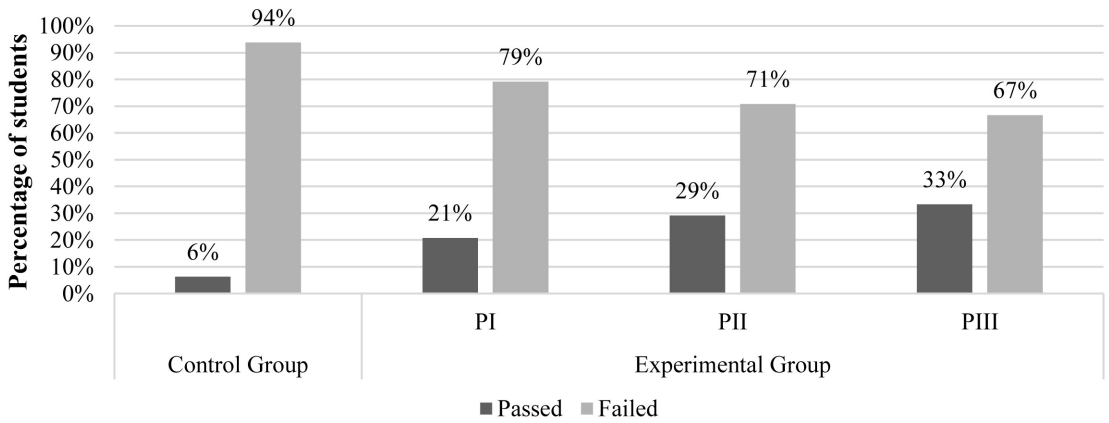

Fig. 8. Module completion status of type III students.

Fig. 8 shows an increase in the proportion of type III students who passed the module after implementing the CMF strategy. In the control group 6% of the sample passed but after implementation of the strategy, the proportion of students who passed increased substantially, up to 33%. The results obtained coincide with what De la Herrán reported [12] and demonstrate that CMFs help to evaluate the conceptual knowledge of students with greater difficulties since it allows them to develop higher-order skills, because they not only understand the concept, but compare, analyze and discriminate which variables are and are not part of the approach, leading to the acquisition of knowledge. Therefore, CMFs seem to have a positive impact on this student profile.

4. Discussion

The purpose of this study was to evaluate the impact of CMFs as a pedagogical strategy on the academic performance of engineering students taking a Materials Science module at a university in Colombia.

After the application of CMFs, there is an increase in the average score obtained in the theoretical component of the three assessments compared to the control group (Fig. 5). This is to be expected because the strategy is focused on this component of the module and as previously cited the strategy allows students to understand the concepts and relate them to each other. It should be noted that the assessments were designed with the purpose of evaluating not only the understanding of concepts, but also the ability to analyze and evaluate what is part of them and what is not, through interpretive problems that articulate concepts with problem solving. For all three assessments, beyond average tendencies, CMFs were found to also improve the lower limit of academic performance (Fig. 6a, 6b, 6c). Additionally, the Mann-Whitney test showed a significant positive difference in the results of the theoretical component between the experimental group and the control group for all assessments (Tables 3, 4, 5). This

confirms that CMFs had a substantive positive impact on students' learning.

The percentage of students who passed increased significantly with the implementation of CMFs (Fig. 7). This is in contrast to the historical trend of the module, where the percentage of students who failed was higher than those that passed. Such a situation was clearly undesirable, even alarming for the university.

Finally, for type III students, who are characterized by having a GPA below 3.24 points, there was an increase in the percentage of students who passed the subject (Fig. 8) after the intervention. In the control group 6% of type III students passed but after implementation of the strategy, this proportion increased substantially, up to 33%. This suggests that CMFs are broadly applicable and can lead to performance improvements across students with varying levels of academic ability. Thus, the implementation of the CMF is suggested in other branches of engineering (electrical, chemical, civil . . .), in the basic themes, which play a key role in the orientation of concepts, which will allow students to generate connections to the understanding of the different engineering phenomena.

Notwithstanding the clear advantages of CMFs as a teaching and learning strategy, this tool is not without its limitations. Key in this respect are familiarization and recall. To elaborate, some students quickly lost the habit of generating CMFs with respect to new issues. In this sense, it is advisable to delve into strategies to maintain continuity of the student to self-regulate their learning using CMFs.

5. Conclusions

This study investigated the effects of CMFs on students' academic performance on the theoretical component of a Materials Science module taught to Engineering students. Each of the three assessments associated with this module contained a theoretical component which allows to determine the ability of students to discover relationships between definitions and phenomena applied to understand, recognize and analyze the fundamentals of material science; that is, the questions were designed for the purpose of evaluating not only the comprehension of students with respect to concepts, but also skills such as the ability to analyze and evaluate what is part of the concepts and discriminate against what does not belong. To this end, the implementation of CMFs sought the development of higher-order skills.

Statistical analyses were carried out to measure the impact of the strategy. The results show that CMFs contribute to the transposition of theoretical content, allowing the student not only to identify and recognize concepts, but to analyze and solve problems. Importantly, CMFs were shown to yield benefits across all types of students, not just those with above average ability based on their prior academic performance. Thus, overall, it can be concluded that there is a positive impact of CMFs on the academic performance of the engineering students in the sample.

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