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Enhancing Mathematics Education through Peer Collaboration: Impact of Collaborative Exam Retakes in Engineering Courses

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ABSTRACT

CONTEXT

Peer learning enhances student engagement and understanding through mutual education. In STEM, collaborative learning is crucial for developing critical thinking and problem-solving skills. Previous studies highlight the benefits of peer learning in creating a supportive learning environment, despite challenges like group dynamics and varying student preparedness.

PURPOSE OR GOAL

This study investigates the impact of peer collaboration during exam retakes on learning outcomes and motivation in Mathematics education. It focuses on whether this approach enhances critical thinking, problem-solving abilities, and overall academic performance in engineering students.

APPROACH OR METHODOLOGY/METHODS

Over three academic years, 290 first-year students in Mathematics I participated. The assessment included an individual exam phase followed by a collaborative phase. Data was collected through structured questionnaires and personal interviews to capture students' perceptions and experiences. The analysis compared experiences in heterogeneous and homogeneous groups based on prior academic performance.

ACTUAL OR ANTICIPATED OUTCOMES

The results show that peer collaboration during exam retakes positively influences motivation and learning outcomes. Students in heterogeneous groups reported higher satisfaction and perceived benefits, suggesting that diverse group compositions foster more effective peer learning dynamics.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Collaborative exam retakes enhance student learning in Mathematics education, particularly in engineering courses. Future research should optimise group formation and integrate technological tools to improve the collaborative learning experience. These findings support student-centred and interactive learning environments.

KEYWORDS

Peer Learning, Collaborative Exam Retakes, Mathematics Education, Engineering Education, Student Motivation.

Introduction

Assessment in higher education is essential for evaluating student learning and achievement. Traditionally, methods have evolved from oral exams to written tests and standardised exams, each with its own advantages and challenges. While standardised tests offer consistency, they often promote rote memorisation and miss the nuances of individual learning. An ideal assessment should not only measure knowledge but also foster critical thinking, creativity, and real-world applicability, balancing fairness, validity, and reliability (Ananiadoui & Claro, 2009; Boud & Bearman, 2024).

In recent decades, educational paradigms have shifted towards holistic, student-centred approaches that emphasise critical thinking, problem-solving, and continuous learning (Campbell et al., 2024; Çelik et al., 2024; Kerman et al., 2024). This shift has led to the rise of authentic assessments, peer evaluations, and active learning, with peer learning emerging as a particularly effective strategy. Peer learning involves students engaging in mutual education and knowledge exchange, benefiting from each other's strengths (Pointon-Haas et al., 2024; Stigmar, 2016).

Peer learning emphasises communication and collaboration, enhancing understanding as students teach one another, which supports self-directed learning, critical thinking, and improved academic performance (Stigmar, 2016; Pointon-Haas et al., 2024; Mínguez-Aroca et al., 2024; Kerman et al., 2024). However, conflicts and varying viewpoints can arise, influenced by the dynamics between students and the instructor. Effective communication and integration of information are crucial for the success of peer learning (Ananiadoui & Claro, 2009; Boud & Bearman, 2024; Campbell et al., 2024).

In STEM education, where innovation and complex problem-solving are key factors, peer learning fosters collaboration, akin to real-world scenarios where multidisciplinary teams address challenges. STEM students gain diverse perspectives and refine their understanding through peer interactions, but the specialised nature of these subjects necessitates accuracy and depth (Çelik et al., 2024; Mínguez-Aroca et al., 2024).

This study explores a novel peer learning approach in mathematics education within engineering, focusing on the impact of collaborative exam retakes. The assessment strategy blends individual accountability with collaborative problem-solving, where students first complete exams individually and then reattempt them in teams, simulating real-world engineering scenarios. If the group score exceeds individual scores, the higher score positively impacts each member's individual grade.

This dual-phase approach leverages group dynamics to deepen understanding, provide immediate feedback, and address misconceptions. Collaboration enables students to articulate reasoning, discuss strategies, and reinforce learning by teaching others, enhancing social and communication skills vital for professional settings. Feedback has been overwhelmingly positive, with students reporting increased motivation, deeper understanding, and improved performance in subsequent assessments, suggesting that the knowledge gained is both profound and lasting.

This paper examines this innovative peer learning approach, its challenges, and broader implications in STEM education, highlighting the potential of collaborative exam retakes to enhance learning outcomes, foster collaboration, and equip students with the competencies needed for continuous, self-directed learning and professional growth.

Methodology

This research was conducted in the "Mathematics I" course, part of the Degrees in Industrial Electronic Engineering and Automation and Mechanical Engineering at the Technical University of Valencia, Spain, over three academic years: 2021/2022, 2022/2023, and 2023/2024. Approximately 100 first-year students enrolled each year, with around 50 students in each

discipline, totalling 290 participants aged 18 to 19 years. The curriculum covered four modules: Complex Numbers, Differential Calculus of Multivariable Functions, Integral Calculus, and Algebra.

The course utilised a continuous assessment methodology with four assessment events per thematic block. The evaluation included two stages: an individual exam phase consisting of short-answer questions and problem-solving tasks lasting 60 to 90 minutes, followed by a collaborative phase where students, grouped into teams of four, retook the same exam in 10 to 30 minutes. If the collaborative exam score exceeded the individual scores, it enhanced each member's score by 10% to 15%.

To evaluate perceptions of the peer learning approach, a survey with Likert scale questions and open-ended questions was administered immediately after the final collaborative exam phase. Participation was voluntary and anonymous, with all participants briefed on the research nature, confidentiality, and their right to withdraw without consequence. Explicit consent was obtained, ensuring that data were anonymised, securely stored, and accessible only to the research team. Additionally, personalised interviews were conducted with students who voluntarily agreed to participate.

Results

Usefulness

The questionnaire aimed to assess the perceived usefulness of peer collaboration during exam retakes in the *Mathematics I* course. Students were asked, "How useful do you find peer collaboration during exam retakes?" with responses ranging from “Not at all useful” to “Extremely useful.” The data shows that 66.2% of students found peer collaboration highly useful, with 38.6% rating it as "Very useful" and 27.6% as "Extremely useful" (see Figure 1). This positive response may indicate that the peer learning model was well-received, as students valued the collaborative dynamics during exams. Only 9.6% of students rated it as "Not very useful" or "Not at all useful."

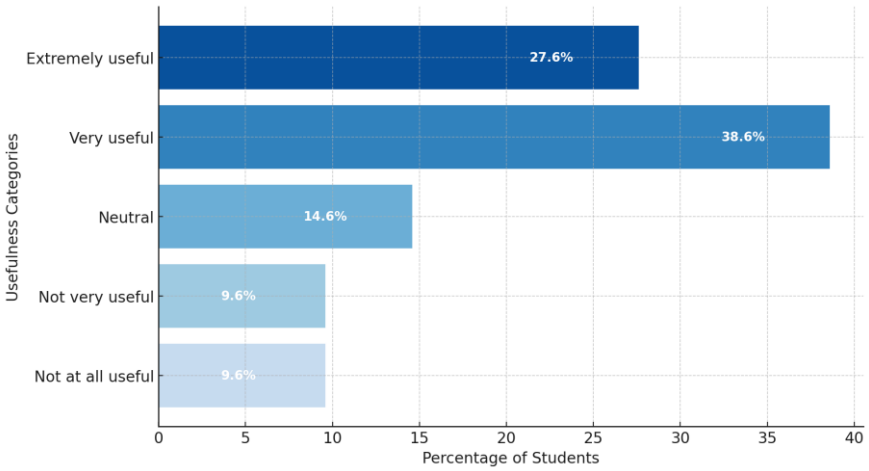

Figure 1: Students' perceived usefulness of peer collaboration during exam retakes

Motivation

The motivation aspect of the questionnaire was designed to assess whether collaborating with peers during exam retakes enhances students' motivation levels. The question asked was: "To what extent did collaborating with peers during exam retakes enhance your motivation?". The options provided ranged from “Not at all” to “Extremely”.

Analysing the responses, it is clear that peer collaboration positively affected student motivation, with 73.4% of students reporting an increase in motivation, ranging from moderate to extreme

levels (see Figure 2). Only 12.4% felt their motivation was not enhanced, indicating that while most students benefit, a minority may find this method less effective.

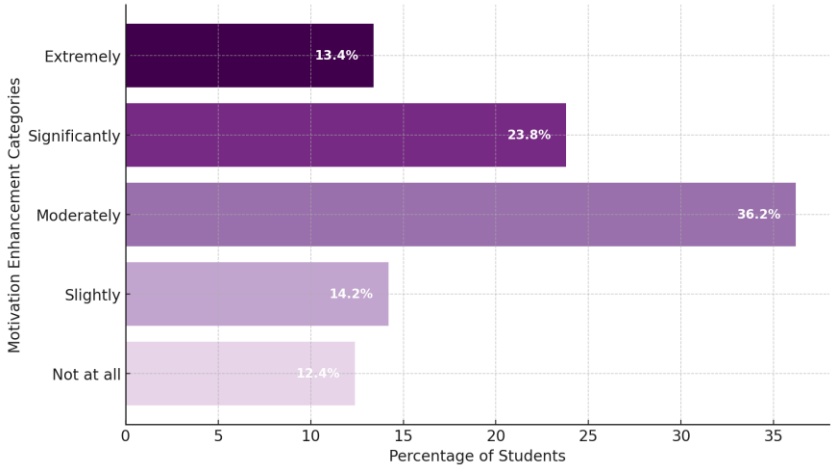

Figure 2: Enhancement of student motivation in collaborative exam retakes

Understanding

The questionnaire asked students if peer collaboration during exam retakes enhanced their understanding of mathematical concepts. The results showed a favourable perception, with 60.7% agreeing or strongly agreeing that collaboration aids comprehension (see Figure 3). Only 7.5% were sceptical, indicating that most students recognise the benefits of collaborative learning for understanding and retention.

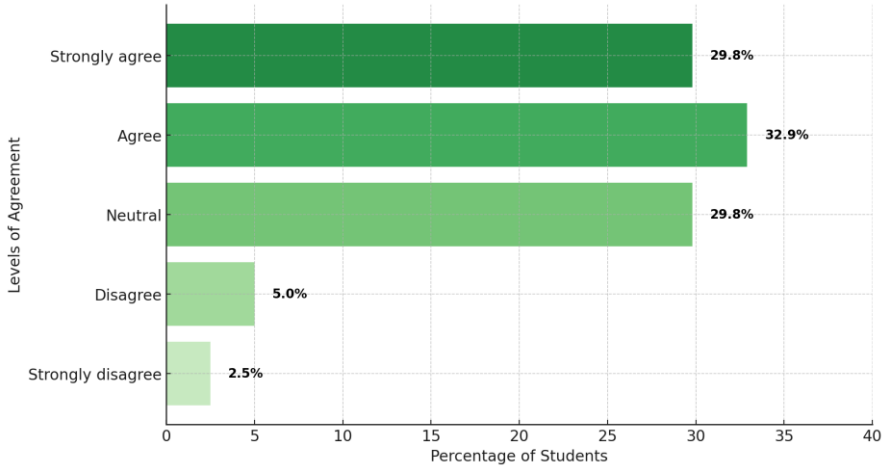

Figure 3: Enhancement of understanding of mathematical concepts

New strategies

The questionnaire explored how often students learned new strategies from peers during exam retakes. The results show that peer learning seems to be beneficial for many, with 33.8% learning new strategies in most questions and 14.5% in nearly every question (see Figure 4). The most common response, "in some of the questions," was chosen by 39.2%, indicating occasional benefits. Only 12% reported learning new strategies rarely or never, suggesting that most students find value in peer interactions, despite varying frequencies.

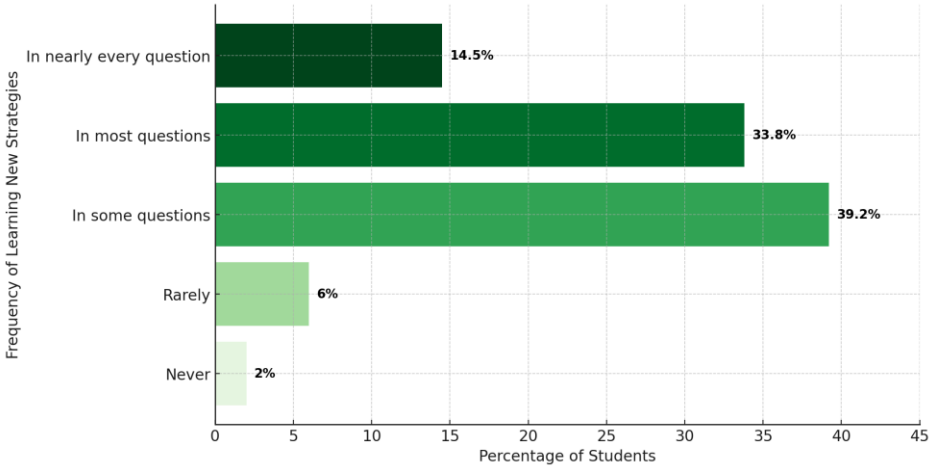

Figure 4: Frequency of students learning new strategies from peers during exam retake

Critical thinking

The questionnaire assessed whether students felt that peer collaboration during exam retakes enhanced their critical thinking skills. The data shows a strong consensus, with 64.2% agreeing or strongly agreeing that collaboration improves these skills (see Figure 5). While 26.4% were neutral, only 9.4% disagreed.

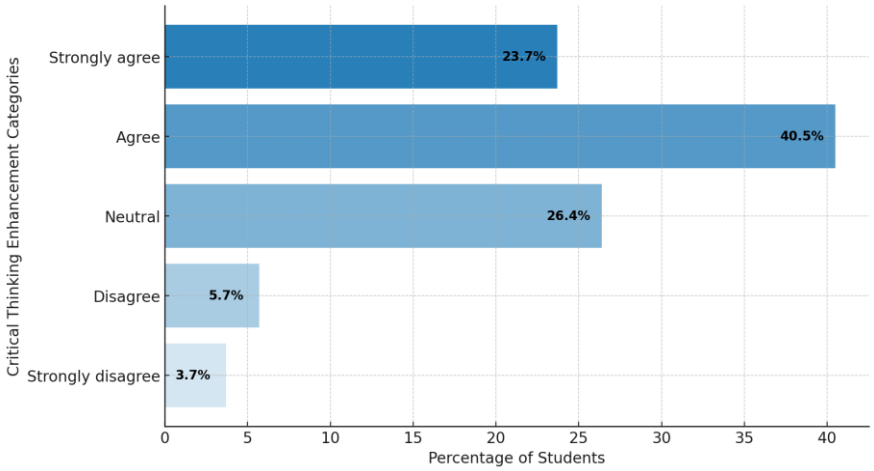

Figure 5: Student responses on the enhancement of critical thinking.

Problem-solving

The questionnaire explored students' perceptions of how peer collaboration during exam retakes affects problem-solving skills. The results show that 64.2% of students agree or strongly agree that collaboration enhances their problem-solving competencies (see Figure 6). A notable 27.6% were neutral, while only 8.3% disagreed, indicating that most students believe peer learning effectively promotes higher-order thinking skills, with minimal dissent.

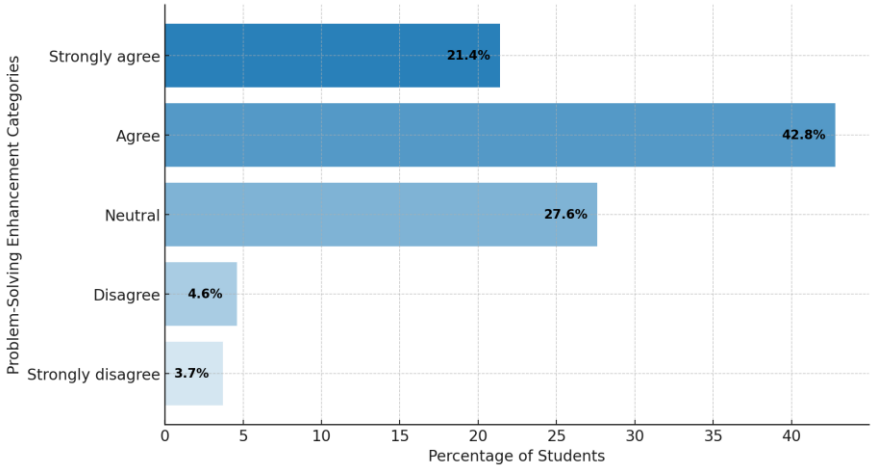

Figure 6: Student responses on the enhancement of problem-solving competencies

Insights from Student Interviews on Exam Retakes

Personal interviews were conducted to gain deeper insights into students' experiences with peer collaboration during exam retakes. A total of 102 interviews were carried out, providing qualitative data that enriched our understanding of students' perceptions and experiences.

Positive Feedback on Peer Collaboration

Most interview responses were very positive about the usefulness of exam retakes facilitated by peer collaboration. Students frequently highlighted how these sessions allowed them to engage actively with the course material in a supportive environment, enhancing their learning outcomes. Specific comments from students included:

- *Collaborating with my peers during the retake helped me grasp concepts that were difficult for me during the individual exam.*
- *The collaborative retake made the learning process more enjoyable and less stressful.*
- *Reviewing the exam content with my group reinforced and clarified key concepts that were initially challenging.*

Feedback on Exam Retakes

A common point of agreement among students was the value of the feedback received during these collaborative sessions. Students described the feedback on exam performance as "extremely positive," noting that it was helpful in correcting misunderstandings and validating the knowledge they had acquired. Specific comments from students included:

- *The detailed feedback we received was instrumental in understanding our mistakes.*
- *I appreciated the immediate and constructive feedback; it boosted my confidence.*
- *Getting feedback during the group exam validated my understanding and highlighted areas needing improvement.*

Drawbacks and Challenges

Despite the predominantly positive feedback, some drawbacks were noted regarding the dynamics of group interaction. A few students reported that sometimes the interaction within their group was not as constructive as desired. Issues such as uneven participation levels and differing levels of preparedness occasionally hindered the effectiveness of the collaboration. Specific comments from students included:

- *Sometimes, not everyone in the group was equally prepared, which made it challenging to work efficiently.*
- *There were times when one or two group members dominated the discussion, making it hard for everyone to contribute.*

- *Occasionally, the collaboration was less effective due to varying levels of engagement among group members.*

Learning and Self-Discovery

A significant theme that emerged from the interviews was the learning and self-discovery facilitated by interacting with peers. Students expressed that through these discussions, they were able to learn from others and uncover their own weaknesses. Specific comments from students included:

- *Interacting with my peers helped me identify my own gaps in understanding.*
- *I learned new problem-solving strategies by listening to my classmates' explanations.*
- *These sessions encouraged me to reflect on my own learning and recognise areas where I needed improvement.*

A note about group formation

Figure 7 illustrates student opinions from two group types: heterogeneous (GHETE) and homogeneous (GHOMO), based on their previous grades. Initially, groups were classified using university entrance scores, with subsequent exams referencing the average of prior grades to ensure consistent performance measurement. Groups were deemed heterogeneous if the standard deviation of the grades within the group exceeded 3.5 points, and homogeneous if the standard deviation was 3.5 points or less. The choice of using the standard deviation as a threshold was made because it captures the overall variability in academic performance within the group.

The data in Figure 7 show that opinions are significantly lower in homogeneous groups compared to heterogeneous groups across factors such as usefulness, motivation, learning, and group participation. Heterogeneous groups benefit from diverse perspectives, enhancing the collaborative experience, while homogeneous groups may have limited dynamics and knowledge exchange, affecting their perception of the activity.

Promoting heterogeneous groups for exam retakes can enhance student satisfaction and performance by fostering a more inclusive and collaborative environment. Further research on group formation is recommended, as group dynamics and other factors can influence the effectiveness of these activities.

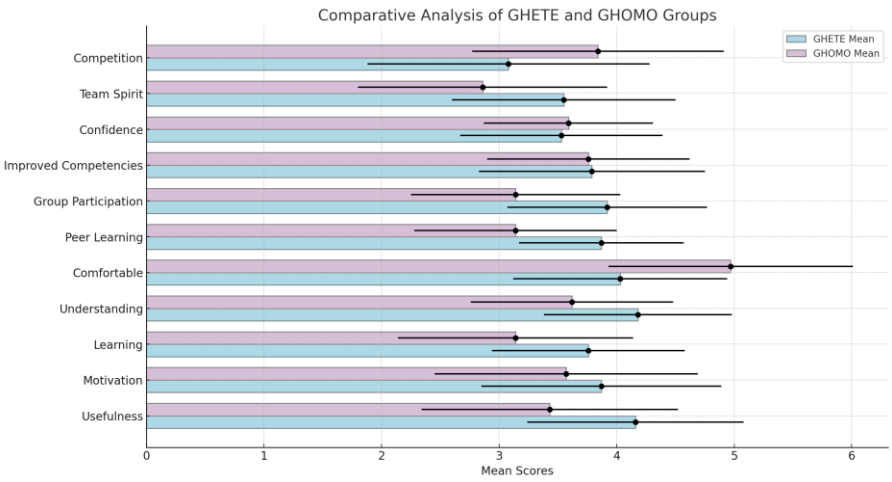

Figure 7: Comparative analysis of the opinions of GHETE and GHOMO groups.

Group vs. Individual Test Performance

Over three academic years (2021/2022, 2022/2023, and 2023/2024), 12 tests were conducted per group, totalling 24 tests where the collaborative exam retake approach was implemented. The average group exam scores consistently exceeded individual scores, with 98.6% of the 384 group exams resulting in higher group scores. Only 1.4% of group exams had scores lower than

the highest individual score, occurring in groups with generally low performances. Further analysis revealed that the average score difference between group scores and individual scores was significantly greater in heterogeneous groups compared to homogeneous groups (p-value = 0.001). Heterogeneous groups had an average score difference of 2.7 points (standard deviation of 1.1), while homogeneous groups had an average difference of 1.1 points (standard deviation of 0.6).

Academic Performance in Peer Learning

Obtaining precise data on student performance is challenging, as tests are independent and concepts are revisited only if a student fails. No specific exams are conducted to track performance improvements. However, in lab practices using Mathematica, where four practical exams align with theoretical sections, students in the collaborative activity scored an average of 7.6 (SD = 1.6), compared to 6.8 (SD = 1.5) for non-participating groups. Statistical analysis (p = 0.032) suggests a positive impact of the collaborative methodology. Both groups had comparable university entrance scores.

Additionally, an ANOVA test compared laboratory scores based on the perceived usefulness of the methodology, revealing significant differences (p-value = 0.048), suggesting a correlation between perceived usefulness and performance. However, potential biases exist, as the data were based on laboratory practices, introducing variables such as familiarity with the software, task complexity, and individual problem-solving approaches specific to laboratory settings.

To verify the significance of the differences between individual and collaborative exam outcomes, we conducted Paired t-tests. The results showed a statistically significant difference between group scores and individual scores (p-value = 0.021), indicating that collaborative exam retakes generally led to higher performance. Additionally, the Paired t-test revealed a significant difference between the group scores and the average of the individual grades within each group (p-value = 0.032). These findings confirm that the collaborative exam approach significantly improves exam outcomes compared to individual efforts alone.

Conclusions

The exploration of peer collaboration within the Mathematics I course has revealed significant benefits and some minor challenges associated with peer-assisted learning, especially in the context of exam retakes. Most students experienced positive outcomes, including improved understanding, increased motivation, and enhanced confidence due to the collaborative approach. The feedback mechanism was particularly appreciated for its immediacy and constructiveness, aiding students in identifying and correcting misconceptions while reinforcing their knowledge.

One of the key elements of this peer collaboration approach is the emphasis on advanced preparation. Knowing that their individual performance will be assessed, students are motivated to prepare thoroughly for the exam beforehand. This preparation helps to mitigate unequal participation within the group, as all members have grappled with the problems and exercises independently prior to the collaborative phase. Additionally, the short time frame allocated for the group retake compels students to quickly compare results and double-check exercises, promoting a focused and efficient group effort where errors can be identified and corrected collaboratively. Furthermore, the incentive of extra points for successful group performance enhances motivation, encouraging students to address individual shortcomings through collective success. However, the study also identified occasional issues in group dynamics, such as unequal participation and varying levels of preparedness among peers. These challenges, while limited, highlight the need for continuous adjustments to optimise the collaborative learning environment. One effective strategy is for teachers to actively monitor and control the group interactions during the collaborative exam retakes. Given that multiple teachers are typically present, they can oversee group dynamics, ensure balanced participation, and provide guidance when necessary, helping to maintain an equitable and productive learning atmosphere.

Future research should focus on refining peer learning methodologies, exploring their application across various disciplines, and integrating advanced technological tools to improve their effectiveness. Additionally, future sessions should consider strategies to enhance group interaction, ensuring more consistent and positive experiences for all participants.

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Universitat Politècnica de València, with reference code P14-27-02-2024.

Statement on AI usage

The Grammarly AI was used to assist with language and spelling corrections in this manuscript. The content and text were originally provided by the authors, and Grammarly was employed solely to correct language errors and typos.

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