Student Perceptions and Beliefs on the Use of Digital Technologies from an Innovation Experience in an Introductory Linear Algebra Course

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***Abstract*—This study addresses a critical gap in mathematics education by examining student perceptions of digital technology integration in an introductory linear algebra course in Chile. Although technology use in higher education is expanding, little is known about how different student groups, such as undergraduate mathematics students and pre-service teachers, engage with these tools in advanced mathematical contexts like linear algebra—a subject essential across Science, Technology, Engineering, Mathematics (STEM) fields but challenging to teach due to its abstract nature. Data from 59 participants were gathered via a questionnaire assessing engagement, perceived benefits, and motivation toward digital tools like SageMath and Canvas Learning Management System (LMS). Reliability analysis and statistical methods, including t-tests, ANOVA, and correlation, were employed to explore group differences and relationships between perceptions and technology use. Findings show that pre-service teachers reported significantly higher motivation ($p < 0.001$) and perceived greater benefits ($p < 0.03$) compared to undergraduates. A strong positive correlation ($r = 0.71$, $p < 0.001$) was found between perceptions of technology's professional relevance and engagement with digital tools. This study contributes to understanding how different student cohorts perceive and use technology in linear algebra education, underscoring the need for tailored strategies in technology-enhanced learning environments.**

***Keywords*—digital technologies, mathematics education, student perceptions, technology integration, linear algebra**

I. Introduction

Linear algebra is a foundational subject in mathematics, essential for a wide range of disciplines such as engineering, physics, computer science, and economics. The importance of linear algebra stems from its role in developing critical thinking and problem-solving skills necessary for understanding abstract mathematical structures and their applications. However, traditional teaching methods—characterized by static content delivery through lectures and individual problem-solving exercises—often fail to engage a diverse student population and address the varied learning styles of modern learners [1, 2]. Research has demonstrated that passive learning methods can limit students' ability to grasp complex, abstract concepts, particularly in fields like mathematics, where conceptual understanding is critical [3, 4]. As a result, there is an increasing need for more interactive and engaging pedagogical approaches that foster deeper learning and student involvement.

Traditional linear algebra courses often rely on lectures that present material in a linear and static fashion. While these methods can be effective for some students, they may hinder others from actively engaging with the material [3]. This often leads to passive learning, where students struggle to connect theoretical concepts with real-world applications, especially in a subject as abstract as linear algebra [5]. Consequently, students may disengage from the learning process, resulting in gaps in conceptual understanding.

Problem-solving is central to learning mathematics, but traditional courses emphasize individual problem-solving tasks that can isolate students and limit opportunities for collaboration. Research has shown that collaborative learning enhances retention and understanding of complex concepts. When students work together, they develop critical thinking and communication skills, which are essential for solving challenging mathematical problems [6]. However, traditional methods often overlook the benefits of collaborative learning, which can increase students' engagement and improve learning outcomes [7, 8].

Linear algebra also includes intricate concepts such as vector spaces, linear transformations, and eigenvalues, which can be difficult to visualize without appropriate tools [9]. The absence of dynamic and interactive visual aids in traditional teaching methods leaves many students struggling to form a solid understanding of these abstract concepts. The need for better visualization tools is critical to improving student outcomes in mathematics courses, as highlighted by [10].

Students in modern classrooms exhibit diverse learning styles, including visual, auditory, and kinesthetic preferences [11]. Traditional teaching methods often fail to accommodate this diversity, leading to disengagement for many students. By integrating interactive learning approaches, educators can create a more inclusive learning environment that caters to these varied preferences. For example, digital platforms allow students to engage with mathematical concepts through visual aids, simulations, and hands-on activities, fostering deeper conceptual understanding [5].

Interactive learning tools, such as computer software and simulations, offer new ways for students to explore and manipulate linear algebra concepts. Technologies like MATLAB, GeoGebra, and SageMath provide dynamic platforms where students can visualize and interact with abstract concepts such as matrices and vector transformations, enhancing their understanding [12]. These tools allow students to bridge the gap between theory and practice, offering real-time feedback and opportunities to experiment

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with mathematical models [13].

Collaborative learning activities, such as group projects and peer teaching, can further enhance student engagement and foster a deeper understanding of linear algebra. Research has demonstrated that collaborative learning encourages communication and teamwork, both essential skills in academic and professional settings [7]. When integrated with digital tools, collaborative activities allow students to share insights and solve problems collectively, improving learning outcomes [5].

Incorporating technology into the classroom—such as interactive whiteboards, online platforms, and tools like SageMath—facilitates dynamic content delivery and fosters student engagement [14]. Platforms such as Kahoot! and Poll Everywhere can be used to create interactive quizzes and polls, encouraging active participation and providing immediate feedback to students [13]. These tools help make abstract concepts more accessible and ensure that students actively engage in their learning process.

The primary objective of this study is to investigate how the integration of digital technologies, specifically interactive tools and collaborative platforms, can enhance student engagement, understanding, and overall learning outcomes in an introductory linear algebra course. Additionally, this research seeks to compare the perceptions and experiences of two distinct groups: undergraduate mathematics students and secondary mathematics pre-service teachers. By focusing on these groups, we aim to identify differences in how digital tools influence their learning experiences and to provide insights that can guide the development of more effective pedagogical approaches.

The urgency of this research is clear. As technological and scientific challenges become more complex, graduates with a solid foundation in linear algebra are increasingly critical. Traditional teaching methods, however, risk widening the gap between academic learning and practical application. This study tackles this issue by exploring how digital technologies can transform the learning experience in linear algebra. By analyzing the perspectives of both undergraduate students and pre-service teachers, we provide essential insights that can drive more effective and engaging pedagogical strategies.

The outcomes of this research could not only improve how linear algebra is taught but also shape the way future educators prepare to teach this vital subject. In a time when computational thinking is indispensable across fields, advancing mathematics education is more pressing than ever.

II. Literature Review

The integration of digital technologies in higher education mathematics, particularly in linear algebra, has garnered increasing attention in recent research. These technologies offer significant potential for enhancing learning experiences, especially in mathematics, where abstract concepts often require innovative instructional methods [15]. Drijvers *et al*. [16] provide a comprehensive framework that categorizes the purposes of digital technologies in mathematics education, including enhancing learning outcomes, understanding cognitive processes, and reshaping curricula and assessments. This framework highlights the multifaceted role of technology in educational contexts, emphasizing the importance of its thoughtful integration into mathematics education.

Research demonstrates that digital technologies have a notably positive impact on students, especially younger learners, by enhancing their engagement and understanding of mathematical concepts [17]. Hlushak *et al*. [18] underscore the scientific and methodological benefits of these tools, particularly in offering robust support for students' mathematical training. Similarly, Aiym *et al*. [19] stress the role of digital technologies in developing logical thinking skills, a critical competency for future mathematics teachers.

In the specific context of linear algebra, digital tools like SageMath and Canvas LMS have proven highly effective in facilitating student engagement and comprehension. These tools allow students to experiment with abstract concepts such as vectors, matrices, and transformations, fostering deeper understanding through manipulation and exploration [20]. The integration of these tools aligns with broader trends towards active learning strategies, which have been shown to significantly improve student outcomes in STEM fields [3]. Active learning encourages a dynamic, participatory approach, enabling students to interact more effectively with the material and improve retention.

The innovative use of digital technologies extends beyond mathematics, reaching interdisciplinary applications such as health pedagogy and mathematical ecology, highlighting their adaptability and educational value [21].

The concept of Society 5.0, promoted by the Japanese government [22], emphasizes a human-centered society where technological innovations are designed to solve societal challenges and improve quality of life. In this context, the integration of digital technologies in mathematics education is linked to broader cultural and educational shifts [23]. However, it is important to acknowledge that some scholars argue many sectors are still operating within the framework of Society 4.0, which focuses on cyber-physical systems. Understanding the transition between these paradigms is crucial for comprehending the evolving role of digital technologies in higher education, particularly in STEM fields. This shift emphasizes the need for educational systems to adapt to technological advancements, incorporating digital tools to enhance learners' motivation and engagement with mathematics [24].

Digital literacy plays a central role in this transformation, as it promotes metacognitive awareness and supports learning through the use of well-designed cognitive tools [25]. The COVID-19 pandemic further accelerated the adoption of digital technologies in education, driving the development of high-tech educational solutions and new pedagogical paradigms [26, 27]. During this period, Sabon *et al*. [28] classified the diverse roles of technology in supporting mathematics education into four primary frameworks, each contributing uniquely to the educational experience.

Students' perceptions of digital technologies are key to understanding how these tools shape their learning experiences. Gasaymeh *et al*. [29] suggest that students form their perceptions based on both formal academic experiences and informal exposure to technology. Reddy *et al*. [30] emphasize the importance of understanding students' perceptions of assistive technologies in higher education, particularly in fields like mathematics. Moreover, educators' views on digital technology influence how students perceive and engage with these tools, further demonstrating the interconnectedness between students' and educators' experiences [31].

Differences in mathematics learning experiences between undergraduate mathematics students and secondary mathematics pre-service teachers are shaped by several factors. Undergraduate students typically encounter mathematics content and pedagogy through embedded coursework tasks [32], while pre-service teachers may experience teaching anxiety or possess distinct learning styles that affect their attitudes toward mathematics and their teaching approaches [33]. Ibrahim *et al.* [34] highlight the importance of addressing pre-service teachers' specific needs, particularly in developing subject knowledge and teaching skills for secondary education.

Pre-service mathematics teachers' readiness for mobile and blended learning environments is another critical consideration [35, 36]. Zeng [37] emphasizes that pre-service teachers should achieve equivalent learning outcomes, regardless of whether their courses are delivered face-to-face, online, or in a hybrid format. Furthermore, pre-service teachers' beliefs and attitudes toward mathematics significantly influence their future classroom practices and, consequently, their students' learning experiences [38–40].

Key competencies such as collaborative skills, pedagogical competence in e-learning, and the ability to design effective problem-based learning activities are vital for pre-service teachers [41–43]. Additionally, studies on ethnomathematics activities and the integration of school mathematics teaching applications in undergraduate courses provide further insights into how these groups of students engage with digital technologies [44, 45].

The novelty of this research lies in its specific focus on comparing the perceptions and experiences of undergraduate mathematics students and pre-service teachers in the context of linear algebra education. While previous studies have examined technology integration in mathematics education broadly, few have investigated how these two distinct groups engage with and perceive digital tools in a specialized, abstract mathematical domain. By exploring these differences, this study fills a critical gap in understanding how digital tools are perceived and utilized by different student populations in the context of challenging mathematical content.

This research offers valuable insights that can inform more targeted approaches to technology integration in linear algebra education. The findings have the potential to influence curriculum design, teacher preparation programs, and the development of digital tools tailored to the distinct needs of undergraduate mathematics students and pre-service teachers. This study contributes to the broader conversation on enhancing mathematics education through technology, supporting the development of strategies that can improve learning outcomes across diverse educational settings.

III. Materials and Methods

A. Objectives

1) General objective

To compare perceptions of the use of digital technology in mathematics learning among undergraduate mathematics students and pre-service secondary mathematics teachers at Pontificia Universidad Católica de Chile.

2) Specific objectives

1) To identify beliefs about the use of digital technology in initial training courses among undergraduate mathematics students and pre-service secondary mathematics teachers.
2) To compare beliefs about the process of learning mathematics using digital technology among undergraduate mathematics students and pre-service secondary mathematics teachers.
3) To compare orientations toward the use of digital technology in mathematical problem solving among undergraduate mathematics students and pre-service secondary mathematics teachers.
4) To compare perceptions of the importance of digital technology in professional development among undergraduate mathematics students and pre-service secondary mathematics teachers.
5) To explore the relationship between beliefs, orientations, and perceptions about the use of digital technology in mathematics learning among undergraduate mathematics students and pre-service secondary mathematics teachers.

B. Type of Study

The study used a descriptive, cross-sectional and comparative design, with a quantitative methodology. Perceptions about the use of digital technology in the learning of mathematics in university students were described and compared according to their career (Mathematics Degree and Mathematics Pedagogy).

C. Characterization of the Sample

The study employed a purposive non-probabilistic sampling method, targeting students from the Faculty of Mathematics at the Pontificia Universidad Católica de Chile. A total of 59 students participated, with 28 being Undergraduate Mathematics Students and 31 being Secondary Mathematics Pre-service Teachers. These students were enrolled in either the "Introduction to Linear Algebra Laboratory" course or the "Calculus 3" course, both of which incorporate laboratory activities designed to facilitate the application of theoretical concepts through interactive digital tools.

D. Instrument

To assess students' perceptions of technology, use in learning mathematics, a self-report questionnaire was developed. Despite an exhaustive search of the literature for existing questionnaires on this topic, no instrument was found that specifically addressed the use of technology in the mathematics domain. Consequently, the questionnaire items were custom designed, drawing inspiration from existing literature on general mathematics beliefs.

The questionnaire consisted of 24 questions, 5 questions collected academic data and 19 of which were directly related to the use of technology in mathematics learning or professional development measured on a Likert scale ranging from 1 to 5, as detailed in Table 1.

Table 1. Questionnaire items

Item description
1. I am excited about learning math with the help of technology.
2. I think I would get better grades if I studied using technology.
3. I think I would learn more by studying using technology.
4. I am more attentive in class when we use technology.
5. I feel more active when learning math with the help of technology.
6. It is easier to learn mathematics with the help of technology.
7. During my learning process, using technology raises different questions than not using it.
8. I like learning math with the help of technology better than without it.
9. I feel more motivated to learn mathematics with the help of technology.
10. I like that in class we use technology to learn.
11. I believe that in my professional future I will have to make use of technology.
12. It is useful to learn how to use technology with my professional development in mind.
13. I think it is more enriching or rewarding to solve a problem without the help of technology.
14. I prefer to solve problems without the help of technology.
15. I prefer to solve problems with the help of technology.
16. Solving a problem with the help of technology is as valuable as solving it without the help of technology.
17. To solve a problem with the help of technology it is not necessary to understand the concepts involved in it.
18. I would like to see more active incorporation of the use of digital technologies in my degree courses.
19. The use of digital technologies in the courses must be incorporated as a formal and qualified instance.

The questionnaire was organized into 6 scales: "Motivation about learning mathematics with the use of technology" (Items 1,8, 9 10) ; "Perceived benefits of using technology for mathematics learning" (Items 2,3,6,7); "Engagement in the mathematics learning process through the use of technology" (Item 4,5); "Technology orientation in mathematical problem solving" (Item 13,14,15,16,17); "Perception of the importance of technology in professional development" (item 11,12); and "Willingness to incorporate technology as a tool in the training process" (item 18,19).

The reliability of the instrument was assessed using Cronbach's alpha (α) [46], a widely recognized statistical coefficient for measuring the internal consistency of educational instruments. The results shown in Table 2 led to adjustments in certain scales. First, item 13 of the scale "Technological orientation in solving mathematical problems" was eliminated. Second, the dimension "Beliefs about the use of technology in university education and professional development" was dissolved. In its place, only the scale "Perception of the importance of technology in professional development" was retained. Despite this reduction, the significance of the data from the eliminated scale warranted its inclusion as separate items in the analysis.

To improve the reliability of the scales, the following adjustments were made. First, item 13 of the scale "Technological orientation in mathematical problem solving" was eliminated. Second, the dimension "Beliefs about the use of technology in university education and professional development" was dissolved. In its place, only the scale "Perception of the importance of technology in professional development" was retained. Despite this reduction, the importance of the data from the eliminated scale warranted its inclusion as standalone items in the analysis.

Table 2. Reliability analysis of the questionnaire

Scale	α before adjustment	α after adjustment
Motivation about learning mathematics with the use of technology.	0.86	0.86
Perceived benefits of using technology for learning mathematics.	0.84	0.84
Engagement in the mathematics learning process using technology.	0.73	0.73
Technology orientation in mathematical problem solving	0.67	0.7
Perception of the importance of technology in professional development.	0.83	0.83

Note: This table presents the cronbach's alpha (α) that each scale had before and after the adjustment, showing an improvement in the scale "Technology orientation in mathematical problem solving".

E. Laboratory Activities

The study leveraged computer-based laboratory activities within the "Introduction to Linear Algebra Laboratory" and "Calculus 3" courses. These activities were designed to facilitate an interactive, asynchronous learning environment using SageMath and Canvas LMS. Students engaged with these tools to explore and manipulate mathematical concepts such as vectors, matrices, and linear transformations. The laboratories provided a platform for students to apply theoretical knowledge, receive immediate feedback, and develop computational skills essential for their academic and professional growth. The design and implementation of these activities were informed by previous research, which demonstrated their effectiveness in enhancing student engagement and understanding [20].

F. Data Analysis Methodology

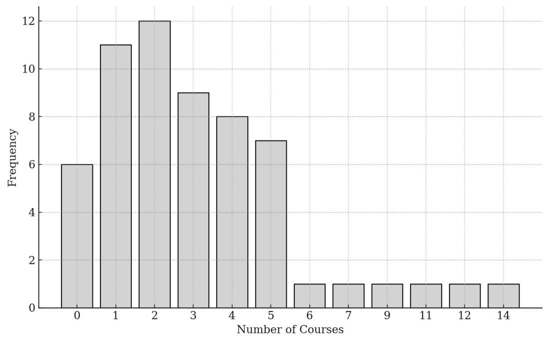
Data analysis was conducted using SPSS and R Studio. Initially, a descriptive analysis of the variables was performed, calculating distributions and measures of central tendency for each variable. A comparative analysis followed, utilizing T-tests, ANOVA, and post hoc tests for ANOVA to identify significant differences between groups. Additionally, relationships between variables were explored through Pearson's correlation to understand the interplay between students' perceptions and their engagement with digital tools in the learning process.

IV. Results and Discussion

A. Results

1) Descriptive analysis of variables

Initially, the analysis focused on the number of courses in which participants systematically utilized technological tools. The data exhibited a positively skewed distribution, indicating that most participants used technology in a limited number of courses (Fig. 1). Specifically, the number of courses ranged from 0 to 14 (out of 25 possible options), with a mode of 2 courses and a mean of 3.19 courses (SD = 2.85). Among the courses mentioned, "Introduction to Linear Algebra" was the most frequently cited, with 40 responses, followed by "Calculus 3" with 25 responses.



Note: The Y-axis shows the number of participants, while the X-axis shows the distribution of the number of courses in which the students had used technological tools systematically.

Fig. 1. Distribution of students according to the number of courses in which technological tools were used.

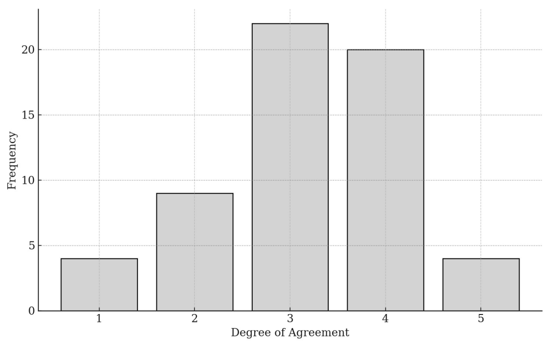
Secondly, regarding participation in the Calculus 3 and Introduction to Linear Algebra laboratories, the analysis revealed that 13 participants did not participate in either laboratory, while 23 participants attended only one of the laboratories (either Calculus 3 or Introduction to Linear Algebra). Additionally, 23 participants were involved in both laboratories. Table 3 provides a more detailed breakdown of the participation in each laboratory.

Table 3. Distribution of students according to their participation in the Introduction to Linear Algebra and Calculus 3 Labs

Laboratory	**Yes, it did participate**	**Did not participate**
Introduction to Linear Algebra	44	15
Calculation 3	25	34

Thirdly, when examining the item "I would like the use of digital technologies to be incorporated more actively in the courses of my career," the results showed a symmetrical distribution.

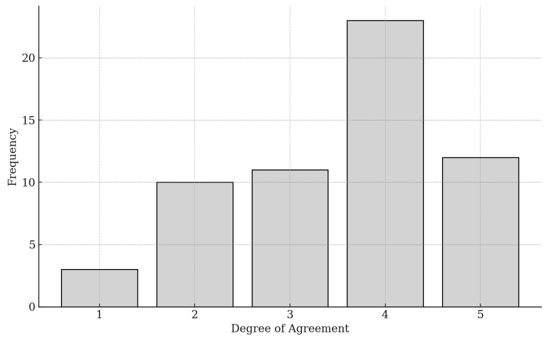
The majority of responses were clustered around the "Neither agree nor disagree" option, with 22 participants selecting this response, followed by 20 participants who chose "Agree" (Fig. 2).



Note: The Y-axis shows the number of respondents while the X-axis shows the 5 possible choices in the degree of agreement.

Fig. 2. Distribution of students according to the degree of agreement regarding the statement *"I would like the use of digital technologies to be more actively incorporated in my degree courses"*.

Fourthly, the analysis of the item "The use of digital technologies in courses should be incorporated as a formal and qualified instance" revealed a negatively skewed distribution (Fig. 3). The most common response was "Agree," selected by 23 participants, followed by "Strongly agree," chosen by 12 participants.



Note: The Y-axis shows the number of respondents while the X-axis shows the 5 possible choices in the degree of agreement.

Fig. 3. Distribution of students according to the degree of agreement regarding the statement "*The use of digital technologies in subjects should be incorporated as a formal and qualified instance"*.

The following 5 paragraphs provide a brief description of the behavior of the questionnaire scales.

The scale "Motivation about learning mathematics through the use of technology" showed a negatively skewed distribution, indicating that responses were concentrated at the highest levels of agreement. The mean score for this scale was 3.5 (SD=0.98), with scores ranging from a minimum of 1 to a maximum of 5 (Fig. 4).

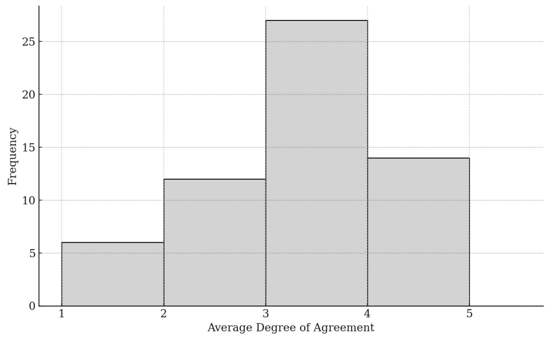
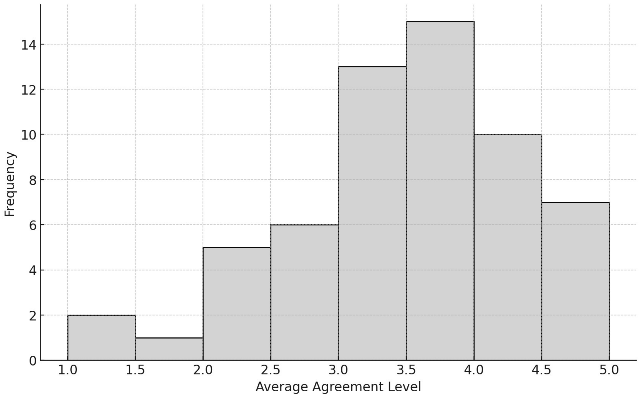


Fig. 4. Average degree of agreement on the scale "Perceived benefits of the use of technology for learning mathematics".

Similarly, the scale "Perceived benefits of the use of technology for learning mathematics" also demonstrated a negatively skewed distribution. However, the average score for this scale was slightly higher than that of the "Motivation" scale, with a mean of 3.62 (SD = 0.87) and a range from 1 to 5 (Fig. 5).

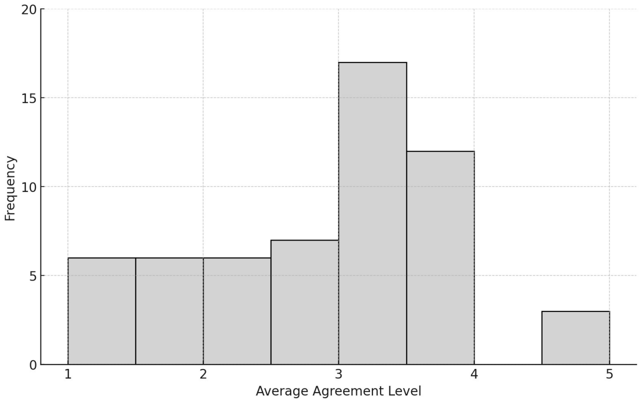
The final scale within this dimension, "Involvement in the mathematics learning process through the use of technology," displayed a distribution with the most frequent scores (modal interval) between 3 and 4, indicating a higher degree of agreement with the statements. The mean score for this scale was 3.15 (SD = 0.99), with responses ranging from 1 to 5 (Fig. 6).

In contrast, the scale "Orientation towards technology in solving mathematical problems" revealed a distribution with the most frequent scores (modal interval) between 2.5 and 3, indicating a lower degree of agreement with the statements (Fig. 7). The mean score for this scale was 3.06 (SD=0.8), with a range of responses from 1.25 to 5.



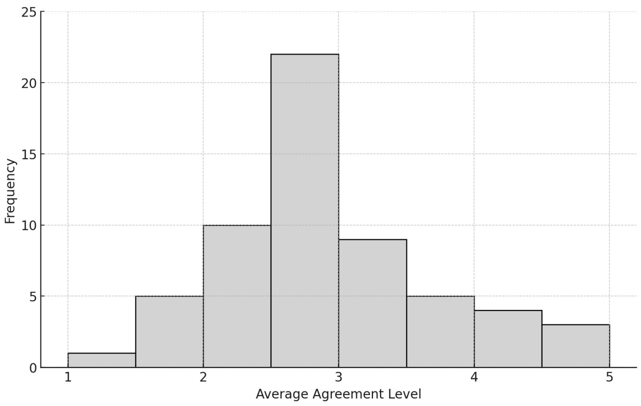
Note: The Y-axis indicates the number of respondents whose average item responses fall within each interval on the X-axis. The X-axis represents the different levels of average agreement, calculated from responses to multiple items. "

Fig. 5. Distribution of students according to the average degree of agreement on the scale *"Perceived benefits of the use of technology for learning mathematics"*.



Note: The Y-axis indicates the number of respondents whose average item responses fall within each interval on the X-axis. The X-axis represents the different levels of average agreement, calculated from responses to multiple items.

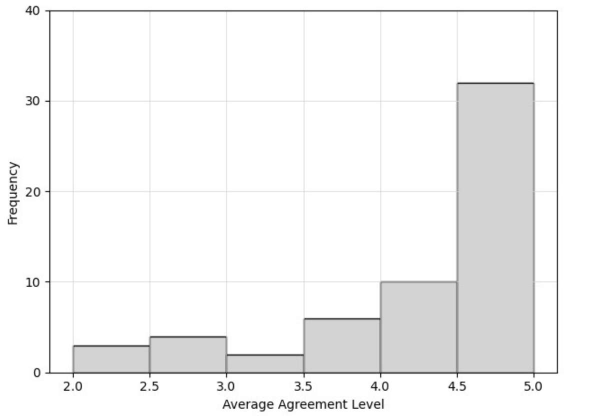
Fig. 6. Distribution of students according to the average degree of agreement on the scale "Involvement in the mathematics learning process through the use of technology".



Note: The Y-axis indicates the number of respondents whose average item responses fall within each interval on the X-axis. The X-axis represents the different levels of average agreement, calculated from responses to multiple items.

Fig. 7. Distribution of students according to the average degree of agreement on the scale "Orientation towards technology in solving mathematical problems".

Finally, the scale "Perception of the importance of technology in professional development" exhibited a negatively skewed distribution, indicating that participants' responses were more concentrated at higher levels of agreement (Fig. 8). The mean degree of agreement for this scale was 4.46 (*SD* = 0.8), with responses ranging from 2 to 5.



Note: The Y-axis indicates the number of respondents whose average item responses fall within each interval on the X-axis. The X-axis represents the different levels of average agreement, calculated from responses to multiple items.

Fig. 8. Distribution of students according to the average degree of agreement on the scale "Perception of the importance of technology in professional development".

2) Comparative analysis of variables

For the comparative analysis, variables measured on the Likert scale were compared based on categorical variables that identified two or more distinct groups. The key categories included: i) the program in which participants were enrolled (Undergraduate Mathematics Students or Secondary Mathematics Pre-service Teachers), ii) participation in the Introduction to Linear Algebra laboratory (Yes or No), and iii) participation in the Calculus 3 laboratory (Yes or No).

The analysis revealed that the variable "Motivation about learning mathematics with the use of technology" showed statistically significant differences based on the program to which students belonged [$t(41.75) = -3.36$, $p = 0.001$]. Specifically, Secondary Mathematics Pre-service Teachers scored significantly higher ($M = 3.8$, $SD = 0.6$) compared to Undergraduate Mathematics Students ($M = 3.08$, $SD = 1.12$).

Additionally, the variable "Perceived benefits of the use of technology for learning mathematics" also demonstrated significant differences according to the students' program [$t(39.31) = -2.21$, $p = 0.03$]. Secondary Mathematics Pre-service Teachers had significantly higher scores ($M = 3.8$, $SD = 0.55$) compared to Undergraduate Mathematics Students ($M = 3.36$, $SD = 1.07$).

Furthermore, the variable "Involvement in the mathematics learning process through the use of technology" showed significant differences in average scores based on the students' program [$t(48.66) = -3.47$, $p = 0.001$]. Secondary Mathematics Pre-service Teachers had significantly higher involvement scores ($M = 3.55$, $SD = 0.76$) compared to students in the Bachelor's Degree in Mathematics program ($M = 2.71$, $SD = 1.05$).

Finally, the variable "Orientation towards technology in solving mathematical problems" also displayed statistically significant differences between the groups based on their program [$t\ (46.34) = 2.35$, $p = 0.02$]. Secondary Mathematics Pre-service Teachers scored significantly lower ($M = 2.83$, $SD = 0.61$) than Undergraduate Mathematics Students ($M = 3.31$, $SD = 0.91$).

In conclusion, regarding the learning of mathematics using technology the results showed that Secondary Mathematics Teachers are more likely to be motivated, perceive greater benefits and present higher levels of involvement than Undergraduate Mathematics Students. However, the latter group tends to be more oriented to the use of technology for mathematical problem solving than the Secondary Mathematics Teacher Trainees.

3) Correlation analysis

For the analysis of relationships between variables, two types of analyses were conducted. First, a Pearson correlation was performed between the variables measured on a Likert scale and the variable "Number of courses in which students had systematically used technology." Second, a correlation matrix was developed to identify all the correlations existing between the different scales.

The analysis revealed a weak but positive correlation between the scale "Motivation about learning mathematics with the use of technology" and the variable "Number of courses in which students had systematically used technology" ($r = 0.29$, $p = 0.02$). This indicates that as the number of courses a student took increased, so did their level of motivation for learning mathematics with the use of technology.

Similarly, a weak but positive correlation was found between the scale "Perceived benefits of the use of technology for learning mathematics" and the variable "Number of courses in which students had systematically used technology" ($r = 0.27$, $p = 0.03$). This suggests that students who participated in more courses tended to perceive greater benefits from using technology in learning mathematics.

As for the correlations between the different scales, several significant results were identified, as shown in Table 4.

Table 4. Correlation matrix between scales

	PIT	PBT	EM	ML	TOM
PIT	1.00	0.61	0.61	0.71	0.51
PBT	0.61	1.00	0.70	0.76	0.57
EM	0.61	0.70	1.00	0.84	0.66
ML	0.71	0.76	0.84	1.00	0.61
TOM	0.51	0.57	0.66	0.61	1.00

Note: The abbreviations used in the table are explained below: PIT (Perception of the importance of technology in professional development), PBT (Perceived benefits of using technology for mathematics learning), EM (Engagement in the mathematics learning process through the use of technology), ML (Motivation about learning mathematics with the use of technology), TOM (Technology orientation in mathematical problem solving).

As shown in Table 4, there were strong positive correlations between the scale "Perception of the importance of technology in professional development" and the scales "Motivation about learning mathematics with the use of technology," "Perceived benefits of the use of technology for learning mathematics," and "Involvement in the process of learning mathematics through the use of technology."

These correlations indicate that students who view the use of technology as important for their professional development tend to be more motivated by technology, perceive more benefits from its use, and are more engaged in the learning process when technology is involved.

Additionally, the correlations between the different scales that make up the dimension "Beliefs about learning mathematics through the use of technology" (i.e., Motivation, Benefits, and Involvement) were also strong and positive.

This suggests the following interpretations:

1) Participants who perceive greater benefits from using technology for learning mathematics tend to be more motivated and more involved in the learning process when it includes technology.
2) Participants who are more motivated to learn mathematics with the help of technology tend to perceive greater benefits and find themselves more engaged in the teaching-learning experience.
3) Participants who are more engaged in the mathematics learning process through technology are generally more motivated to use technological tools and perceive greater benefits from their use in learning.

Finally, Table 4 also highlighted a strong but negative correlation between the scale "Orientation towards technology in solving mathematical problems" and the scales "Motivation about learning mathematics with the use of technology," "Perceived benefits of using technology for learning mathematics," and "Involvement in the process of learning mathematics through the use of technology." This indicates that participants who are more oriented towards using technology in mathematical problem-solving tend to be less motivated about learning through technology, perceive fewer benefits from using technological tools for mathematical learning, and are less engaged in the teaching experience when it involves technology.

4) Summary of results

This study sought to compare perceptions about the use of digital technology in mathematics learning among undergraduate mathematics students and pre-service high school mathematics teachers at the Pontificia Universidad Católica de Chile. The analysis yielded several key insights:

Motivation and Perceived Benefits: Secondary Mathematics Pre-service Teachers demonstrated significantly higher motivation and perceived benefits from using technology in learning mathematics compared to Undergraduate Mathematics Students.

This indicates a stronger alignment between technology use and the educational experiences of pre-service teachers.

Involvement in the Learning Process: Similarly, Secondary Mathematics Pre-service Teachers reported greater involvement in the learning process when technology was employed, underscoring the positive impact of technology on their engagement in mathematics education.

Orientation Towards Technology in Problem Solving: An interesting finding was that students who were more oriented towards using technology for mathematical problem-solving tended to show lower motivation, perceive fewer benefits, and exhibit less involvement in the learning process when technology was integrated.

All of these results are shown summarized in Fig. 9. Along with this, these key insights suggest a potential disconnect between the practical application of technology in problem-solving and its broader perceived value in the learning experience.

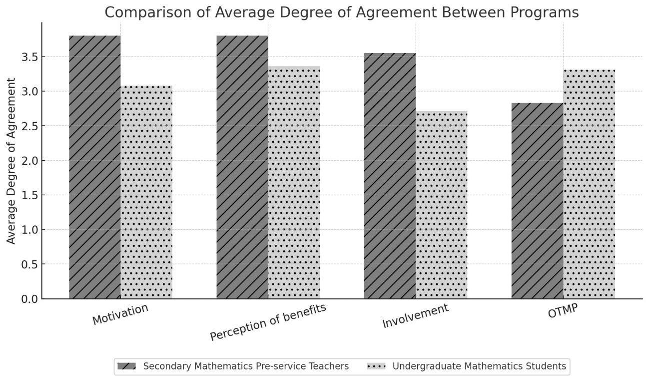


Fig. 9. Average comparison between variables among the two groups.

Correlation Findings: Strong positive correlations were observed between the perception of the importance of technology in professional development and other scales, including motivation, perceived benefits, and involvement.

This indicates that students who recognize the value of technology for their future careers are more likely to engage positively with it in their studies. Conversely, a strong negative correlation was found between the orientation towards technology in problem-solving and the same scales, suggesting that students who focus on technology for problem-solving may be less enthusiastic about its broader application in learning.

In summary, the results highlight the nuanced relationship between students' perceptions of digital technology, their motivation, involvement, and perceived benefits in mathematics education. While technology can significantly enhance the learning experience, its impact is influenced by how students perceive its role in both problem-solving and their future professional development.

B. Discussion

The results of this study emphasize the pivotal role of digital technologies in shaping student engagement, motivation, and perceived benefits in mathematics education. However, the degree to which these technologies impact students vary significantly across different student groups, particularly between Secondary Mathematics Pre-service Teachers and Undergraduate Mathematics Students. While our findings support broader research indicating the potential of digital tools to enhance learning experiences, they also highlight the complexities involved in effectively implementing these tools across diverse educational contexts.

For Secondary Mathematics Pre-service Teachers, the integration of digital technologies appears to align well with their educational objectives, fostering a higher level of motivation and engagement. This outcome is consistent with existing research demonstrating the positive impact of digital tools on teacher education, particularly in preparing future educators to integrate technology into their instructional practices [15, 16]. The positive reception of these tools among pre-service teachers suggests that technology plays a crucial role in helping them develop pedagogical strategies that enhance classroom outcomes.

This alignment with previous research strengthens the argument for incorporating digital technologies into teacher preparation programs. The results suggest that digital tools not only improve pre-service teachers' motivation and engagement but may also have long-term implications for the quality of mathematics instruction they will provide in the future.

In contrast, Undergraduate Mathematics Students showed a stronger preference for using digital technologies specifically for mathematical problem-solving, with higher engagement in this context. This finding aligns with research indicating that digital tools can significantly enhance understanding and retention of mathematical concepts, particularly among students with a more specialized focus [17]. The more pronounced engagement in problem-solving can be attributed to the curriculum's focus on developing strong analytical and computational skills, where such tools are pivotal.

These divergent responses highlight that the effectiveness of digital technologies in mathematics education is context dependent. This supports Borba's [4] argument that the impact of digital tools must be considered within the specific contexts of educational equity, access, and student needs. Furthermore, Drijvers *et al*. [16] stress the importance of aligning digital tools with well-defined learning goals, which our findings reinforce, indicating that technology integration should be tailored to each student group's specific educational objectives.

While some studies report uniformly positive outcomes across various student groups [30], our results suggest a more nuanced perspective. Even with proper integration, different groups of students may benefit in different ways, which complicates the notion of universal applicability for digital tools in education. This highlights the need for a tailored approach, particularly when addressing the specific needs of diverse student populations.

The findings of this study underscore the importance of considering not only the use of digital tools but also how these tools interact with specific curriculum goals and student characteristics. Future research should continue to explore how factors such as previous experience with technology, instructional strategies, and student support mechanisms influence the perceived effectiveness of digital tools.

Additionally, longitudinal studies could provide insights into the long-term effects of early exposure to these technologies on students' academic trajectories and professional development.

In conclusion, while the results of this study generally support the benefits of digital technologies in mathematics education, they also reveal key differences in how these tools are perceived and used by different student groups. These findings call for more differentiated and thoughtful approaches to technology integration, ensuring that the unique needs of various learners are considered to maximize the potential of digital tools in enhancing mathematics education.

V. Conclusion

This study examined student perceptions of digital technology use in mathematics learning, specifically focusing on an introductory linear algebra course and Calculus 3 at the Pontificia Universidad Católica de Chile. The research aimed to understand how Secondary Mathematics Pre-service Teachers and Undergraduate Mathematics Students engage with and perceive digital tools in their education. The findings revealed significant differences between the groups, achieving the study's primary objective.

The study found that Secondary Mathematics Pre-service Teachers demonstrated higher motivation, perceived greater benefits, and showed more involvement with digital technologies, while Undergraduate Mathematics Students exhibited a more cautious approach, particularly in mathematical problem-solving contexts. The impact of digital tools varied depending on the student group and their educational goals. These results underscore the importance of customizing digital technology integration to meet the distinct needs and learning objectives of different student populations. The study adds to the growing body of literature on digital tools in mathematics education and emphasizes the necessity of a tailored approach.

However, the study had some limitations. The small sample size, limited to participants from a single institution, affects the generalizability of the findings. Additionally, the focus on specific courses, such as linear algebra and calculus, may limit its applicability to other areas of mathematics education. Furthermore, the study only examined short-term impacts of digital tool integration, without tracking long-term effects on student learning or professional development.

This research offers several recommendations. Students should actively engage with digital tools provided in their coursework and offer constructive feedback on the effectiveness of these resources. Educators should tailor the integration of digital tools to align with the goals of specific programs and the unique needs of students, while regularly assessing their impact on learning and engagement. For course developers, there is a need to design curricula that incorporate a range of digital tools aligned with program objectives, in collaboration with educators to ensure these resources support learning outcomes. Policymakers in higher education should allocate resources for continuous training in digital technology integration and develop policies that encourage innovative uses of technology in mathematics education. Digital companies can contribute by partnering with educational institutions to create tools that address specific student needs, incorporating feedback from both educators and students during product development.

Future research should explore how early exposure to digital tools influences students' professional practices, particularly through longitudinal studies that track graduates' progress over time. It is also necessary to investigate the effectiveness of specific types of digital tools across a broader range of mathematics subjects. Additionally, research should examine how cultural and socioeconomic factors influence students' engagement with digital technologies in mathematics education.

In conclusion, this study highlights the complex relationship between digital technology integration and mathematics education. By adopting a nuanced approach that considers the diverse needs of student groups, educational institutions can enhance learning experiences and better prepare students for their future academic and professional endeavors. The findings emphasize the need for ongoing research and thoughtful implementation strategies to maximize the benefits of digital tools across diverse student populations in mathematics education.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Carlos Eduardo Rojas Bruna (CRB) conducted the research, designed the study, and coordinated the overall project. CRB also contributed to the development of the methodology, the design of the questionnaire, and the interpretation of the results. Mahsa Allahbakhshi (MA) assisted in the design of the study and provided critical insights into the theoretical framework. MA also contributed to the statistical analysis and the interpretation of the data. Constanza Verdugo Álvarez (CVA) analyzed the data, including performing the statistical analysis such as reliability assessment and correlation analysis. CVA also contributed to the literature review and assisted in drafting the manuscript. All authors collaborated on writing the manuscript, provided feedback during the drafting process, and approved the final version.

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