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Potential of Social Robots and ICTs in Higher Education: Enhancing Complex Thinking and Meta-Competencies

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ABSTRACT: Considering the emerging trends in higher education to implement innovative pedagogical strategies and tools, this study examines the role of Social Robotics (SR) and Information Communication Technologies (ICTs) in enhancing classroom performance and fostering meta-competencies such as scientific, critical, innovative, and systemic thinking. Therefore, a field study was conducted with 106 students from Ibero-American universities, exploring their perceptions of SR through a mixed-methods approach. The objective was to determine the level of acceptance and effectiveness of SR in expanding the learning process. Data were analyzed using Spearman's correlation, revealing significant positive associations between SR implementation and classroom engagement, with students reporting increased general interest in class ($\varrho = 0.741$, $p < 0.001$) and a faster perception of time ($\varrho = 0.679$, $p < 0.001$). Despite these benefits, challenges such as high costs and technical barriers limit widespread SR adoption. However, SR holds significant potential to enhance the quality of higher education, contributing to ongoing efforts to integrate technological tools that prepare students for future challenges and uncertainties. The study recommends further research to evaluate SR's long-term effects and scalability.

Keywords: online education, social robotics, complex thinking, quality of education, higher education, innovational education.

I. INTRODUCTION

Robotics can be understood as the set of techniques used to design and construct robots and devices that perform work generally in substitution or complementation of human labor. In this sense, robots as potential tools have been created to try to emulate various human capabilities even so that, at some point, they can possibly go beyond people's physical and mental abilities [1]. This, despite the challenges and vicissitudes involved in the possibility that the capabilities sought to be reproduced in these machines may or may not include autonomy. Thus, all this can lead to scenarios that open the door to new challenges related to the potential limits that can be set between robots and humans, especially when the purpose is to make them become as similar as possible to humans, even at an anthropomorphic level. Apart from the fact that some human abilities can be fostered in a machine that could, in time, project all those attributes that, on an ontological level, make man what he is as a species. For all the above, robotics has always been understood then as an essential manifestation and indicator of the technological progress of human society [2].

In this sense, it is clear that within the enormous multiplicity of functions that can be developed in robots, there is the possibility that they can teach as well as transmit information to humans. This, given their versatility in terms of vast information storage capacity. All this, considering that they are increasingly seeking to improve many of their specifications, among which memory stands out as well as other human characteristics including motor skills, body expression, and even in some cases, gesticulation [3, 4].

Therefore, robots are increasingly designed to emulate human qualities in general, among which are, for example, the ability to interact with people, given that their raison d'être must do precisely with the solution of problems in the service of man. This situation means several benefits among people, among which stand out the possibilities of generating empathy, the ability to relate in a more extroverted way, and the options to strengthen communication between people and machines. In other words, it can be said that the evolution of robotics is becoming more and more consolidated, and with it the human vision that robots can, from practically any perspective, help people consider their full potential for interaction with humans [5, 6].

It is at this point where social robotics (SR) arises, which is based on the interaction of robots with people in a natural and interpersonal way; all this with the purpose of achieving positive results in areas such as education, health, entertainment, communication, and other spaces where teamwork and collaboration are required [7]. Thus, the goal of SR is to create competent machines and partners for humans that can complement certain challenging tasks to improve people's quality of life [8]. Therefore, when robots are designed, they should communicate naturally with people trying to involve capabilities, not only at a cognitive level but also at an emotional level, to provide effective social support related to their programmed tasks. In other words, robots will eventually need to attain a wide range of socio-cognitive skills in order to better understand human behavior and be intuitively understood by people [9].

Hence, SR can be used in education to make robots act as tutors and better complement the teacher's work in higher education [7]. A situation that may represent a considerable advance over the traditional way of teaching. Even though robots have not yet achieved massification in classrooms due to their high costs, challenges at the level of promoting the academy's advantages, and training challenges for users of this type of technology [10]. Consequently, SR is beginning to be tested in education and its approach gravitates in two main directions. The first, advocates the benefits of robots in effective and efficient instruction and is more focused on supporting the teacher in the classroom. The second is more focused on meeting the student's impressions and learning needs. In this sense, there are some concerns about how, at least for now, robots should not replace humans, so the challenges are socioemotional, educational, and even legal. This does not mean that in certain studies, SR does not have a post-potential, it only shows how there are challenges to overcome at the level of design, role assignment, and understanding that SR is a technological resource to accompany the work of the teacher [11–13].

1. RELATED WORK

Early applications of SR predominantly focused on STEM education, using robots to teach programming and computational thinking. However, the current landscape has broadened, with SR being employed as tutors, teaching assistants, and even companions in various educational levels, including higher education. Guggemos et al. [14] discuss the roles that robots like Nao and Pepper play in these contexts, highlighting their effectiveness in language learning and collaborative tasks.

Social robots are increasingly designed to foster active learning and collaboration. For example, Rosenberg-Kima et al. [15] implemented robots as facilitators in small-group activities in higher education, demonstrating that such interactions can significantly improve engagement and time management compared to traditional human facilitation. Similarly, Donnermann et al. [16] found that long-term use of adaptive robotic tutors in university courses led to measurable improvements in student motivation and exam performance.

Research consistently shows that SR can positively impact both cognitive and socio-emotional learning outcomes. Studies suggest that SR's physical and interactive presence provides an advantage over virtual agents, enhancing students' attention, engagement, and willingness to participate in educational activities. For instance, Belpaeme et al. [11] demonstrated that robot-mediated interactions could lead to improved learning gains, especially when tailored to individual needs. Ramírez-Montoya et al. [17] also found that SR, when integrated within information and communication technologies (ICTs) frameworks, can support complex thinking by enabling systemic, scientific, and innovative approaches to problem-solving, which are essential for developing meta-competencies in higher education.Despite these promising outcomes, several challenges and limitations have emerged. High costs and technical barriers restrict widespread adoption, particularly in underfunded institutions. Moreover, the ethical implications of SR, including concerns about privacy, dependency, and autonomy, remain points of contention. Formosa [18] discusses the ethical conflicts between robots' growing autonomy and human autonomy, emphasizing the need for a balanced approach in designing and regulating SR systems. Similarly, Smakman et al. [19] highlight the importance of developing moral guidelines to address these challenges effectively, especially as SR becomes increasingly embedded in educational settings.

The effectiveness of SR also varies across educational levels and contexts. While studies report higher effectiveness in early childhood and primary education, where SR is often used to teach basic skills and foster engagement, the results are mixed in higher education settings [11, 14]. This discrepancy suggests that although SR is well-suited for engaging younger learners, its application in complex, self-directed learning environments typical of higher education requires further exploration and customization. Ramírez-Montoya et al. [17] emphasize that higher education institutions must align SR implementation with the competencies required in complex professional and social contexts, suggesting that a structured integration of SR with ICTs could effectively foster the development of meta-competencies like critical thinking, adaptability, and innovation.

Moreover, research indicates that stakeholder attitudes toward SR implementation vary widely based on socio-demographic factors, including age, experience with technology, and socio-economic background. Studies such as those by Smakman et al. [19] and Byrne et al. [20] categorize these attitudes into profiles ranging from enthusiastic support to skepticism. This variation underscores the need for strategies that address these diverse perspectives and ensure alignment among stakeholders to enhance SR's impact and effectiveness in educational settings.

A current challenge is the perception that physical presence in a classroom is not essential, especially with the prevalence of online teaching methods. Nonetheless, evidence suggests that the inclusion of SR, alongside tools like ICTs, can enrich educational experiences, similar to how international professors use online conference platforms to conduct classes effectively [10, 21]. As SR continues to integrate with ICTs, it is positioned to complement and enhance these digital tools, thus supporting both synchronous and asynchronous communication in classrooms and improving the overall educational process.

Building upon the previous discussions about SR, it is crucial to acknowledge the significance of ICTs as essential tools in contemporary educational models. While ICTs are already extensively used in classrooms, this does not imply that innovations with new applications or devices are not continuously being developed to further enhance and improve teaching processes. In fact, as SR becomes more prevalent in academia, ICTs will play a pivotal role in facilitating not only the exchange of information but also in fostering synchronous and asynchronous dialogue among participants within the classroom setting [6, 22, 23].

It is evident that education undergoes continuous transformation alongside technological advancements. In this context, the importance of fostering meta-competences among students becomes apparent, emphasizing the development of higher-order thinking skills. This epistemological construct and paradigm underscore the significance of implementing strategies to enhance learning, particularly in higher education. By doing so, it becomes possible to cultivate a workforce of professionals equipped with comprehensive skills, enabling them to propose efficient solutions to the myriads of challenges faced by contemporary societies [17, 24, 25].

Despite the varied perspectives on SR's impact in education, the current research shows both positive outcomes in learning engagement and concerns about implementation limitations. Some studies demonstrate a clear positive impact of SR on learning outcomes and student engagement [11, 25, 26], others reveal concerns and limitations surrounding their implementation [12] and others did not find any relationship [11]. Therefore, further research is essential to better understand SR's influence on educational environments and to establish best practices for its integration.

2. PROPOSED HYPOTHESIS

This research analyzes the impact of SR in the education and research field by enhancing higher education classes through the development of meta competencies in students to indorse complex thinking in scientific research. Therefore, five hypotheses are considered:

A higher level of importance of SR implementation promotes a higher frequency of use of these technologies and vice versa.

- The level of importance of SR implementation in education is related to academic performance improvement.
- The frequency of the potential use of SR is related to academic performance improvement.
- The level of importance of SR implementation in education is related to excellence in education.

In addition, two types of indicators and five classroom performance variables are analyzed:

1. Academic Performance that has the causal variable of importance of implementation. The following classroom performance criteria is considered:
- General interest as a student in all the staging (preparation) of class by the teacher.
- Increased feeling that time ran faster in class.
- Increased feeling of memorizing certain ideas and concepts more easily.
2. Excellence in Education that has the causal variable of frequency of potential use. The classroom performance criteria considered are:
- Enhanced education due to new teaching strategies.
- Increased perception that the teacher and the provider institution are at the forefront of techniques to teach and improve learning.

Based on the premise that SR, when supported by ICTs, holds immense potential for enhancing communication and information exchange in higher education classes, a pilot study was conducted across three sections of the "Research and Writing Scientific Articles" course. The first two sections were carried out asynchronously, while the last section was conducted synchronously. The entire class was offered remotely, with the teacher located in Spain, the technical team situated in Mexico, and the students dispersed between Mexico, Bolivia, and Spain.

Throughout the pilot study, SR was implemented as the central tool, and its interaction with other important tools, such as ICTs, was analyzed. Subsequently, after the conclusion of the class, a survey was administered to validate the hypothesis regarding the potential of these technological resources to support the teacher's work holistically and foster learning in diverse fields of study within higher education. The analysis led to the conclusion that while there is still a significant scope for adopting improvements to facilitate the use of technological resources like SR within the classroom, the quality of online higher education tends to enhance considerably. Most students not only perceive SR as instrumental in constructing better and innovative learning processes but also find that it stimulates their active participation in class. Therefore, the analysis allows concluding that despite the high margin in terms of improvements that can still be adopted even to facilitate the use of technological resources such as RS within the classroom. The quality of online higher education tends to improve significantly since most students not only feel that SR helps in the construction of better and innovative learning processes, but also that it stimulates student participation in class.

II. MATERIAL AND METHOD

A mixed approach was used for this research, since techniques that involve the combination of theoretical and epistemological perspectives, points of view as well as qualitative and quantitative methods were considered. All this, in a study that aims to corroborate, through the results obtained, the hypothesis formulated throughout the proposal as the central object of study [27, 28].

The pilot study was implemented in three phases: two asynchronous sessions followed by a synchronous session. Participants, including students and professors from diverse academic backgrounds, were required to attend all three sessions to ensure consistent exposure to the educational interventions. These sessions were designed to introduce and deepen participants' understanding of scientific research methodologies.

1. PARTICIPANT RECRUITMENT AND SAMPLING

Participants were recruited from various higher education institutions, including Universidad Autónoma de México, Tecnológico de Monterrey, among others. Recruitment strategies included direct invitations to students during university lectures and digital outreach via email and social media platforms. The selection criteria were designed to encompass a diverse demographic, ensuring a representative sample of the population across Mexico, Bolivia, and Spain. Initially, 118 respondents were considered, and after rigorous data cleaning processes, the final sample comprised 106 participants who met all the study requirements [30].

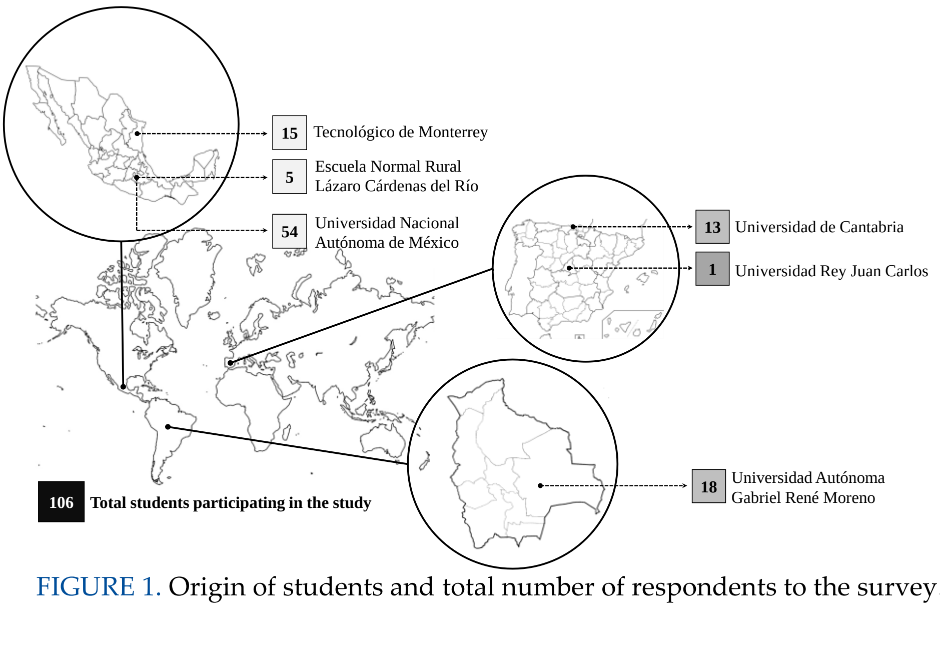

FIGURE 1. Origin of students and total number of respondents to the survey.

In this study some of the students participated independently after being invited to participate in the virtual class to be taught about scientific research; while other students received the class, within some of the sessions of a face-to-face university course led by a professor interested in participating in the pilot. Therefore, the current proposal carries out a pilot for different higher education students (under-graduate and graduate), who were tracked through different media and invited to a class in scientific research. Likewise, after learning about the proposal, some professors accepted to incorporate the present pilot in their classes as a complementary module.

Subsequently, the entire set of students (see Figure 1), in this case from Mexico, Bolivia and Spain, as a vital condition had to participate previously in both session 1 and session 2, which were carried out asynchronously. Later, all of them also had to participate without exception in session 3, which was carried out synchronously.

In this manner (see Figure 2), the three sessions were supported with the central technological tool of this study, namely social robotics (SR) which requires as direct tools, for instance, a NAO Robot, computers with integrated camera and microphone, software to configure the robot script (Choregraphe ®), besides a fast Internet connection.

In the same way, ICTs were adopted also which requires as direct tools, in this case, email (Outlook), video chat (Zoom), instant messaging application for telephones (WhatsApp), office suite (Microsoft Word, Excel, Power Point, among others). All this given that since these are distance classes, the intervention of these latter are also strategic in order to offer the sessions according to plan and to guarantee the improvement of the higher education class as well developing meta-competencies in students in order to indorse complex thinking just like theory suggests.

It is relevant to add with respect to this last idea that the central theme addressed in the pilot in scientific research, apart from the implementation of technological resources, also involves essential aspects that may have an impact on the development of the competence of reasoning for complexity. All this as it happens, in the first place, with scientific thinking as students learn to reproduce and replicate works through research papers and rigorous academic proposals. Secondly, with critical thinking to identify objective sources of information and verify their theoretical validity. Thirdly, with innovative thinking since students can also propose new methods or techniques for the formulation of unpublished research. Fourthly, and lastly, with systemic thinking to be able to take into consideration all the elements that make up research and its relationship with other disciplines when structuring an article.

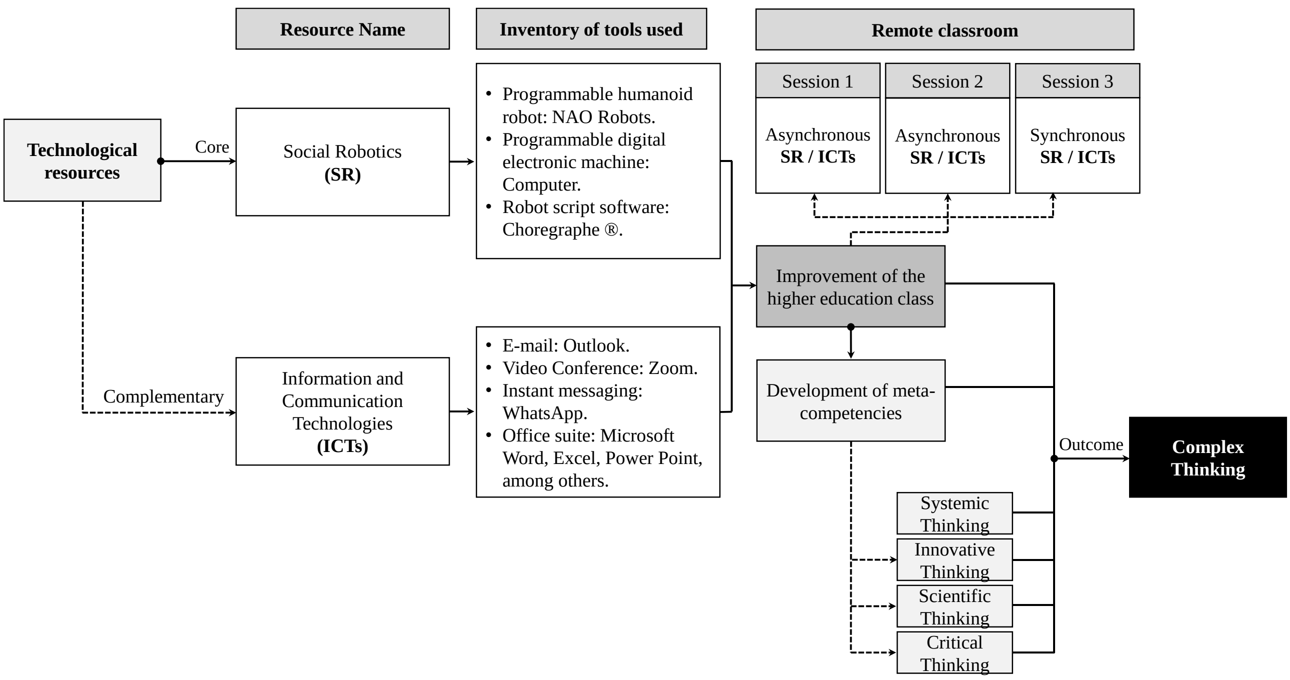

FIGURE 2. Technological resources and tools adopted in the sessions to promote complex thinking.

2. SURVEY DESIGN AND VALIDATION

After the completion of all sessions the 106 participants and students in this pilot are invited to answer a survey inquiring about the impact of SR in addition to its relationship with reasoning for complexity to enhance learning processes.

Within the survey, several questions are asked in order to recognize the level of importance of SR and the perception of technological resources in the classroom, including SR as the central resource of this research, as shown in Table 1. To measure the performance of SR, the questions represented in Table 2 were asked, which are based on all the experience of the interviewees in the pilot; all of this, on six indicators that can measure the quality of teaching in the classroom.

Table 1. Questions about the level of importance and frequency of potential use of SR for classroom improvement.

Question 1	Possible answers 1	Question 2	Possible answers 2
How important should SR be implemented to increase your attention as a student?	Very Important	What is the frequency of potential use of SR to increase the quality of the education service offered by the teacher and the institution?	Always
	Important		Almost Always
	Neutral		Sometimes
	Slightly Important		Seldom
	Not Important		Never

Table 2. Classroom performance questions by RS use.

	According to your perception, in what percentage have the following elements changed in the classroom thanks to the use of SR?	**%**
	Aspects	
Academic Performance	General interest as a student in all the staging (preparation) of class by the teacher.	
	Increased feeling that time ran faster in class.	
	Increased feeling of memorizing certain ideas and concepts more easily.	
Excellence in Education	Enhanced education due to these new teaching strategies.	
	Increased perception that the teacher and the provider institution are at the forefront of techniques to teach and improve learning.	

Table 2 uses the responses in a Likert response scale: (1) Not Important; (2) Slightly Important; (3) Neutral; (4) Important; (5) Very Important. Besides, the indicators in Table 2 reflect components of academic performance and excellence in education, which together can measure the quality of classes in higher education. In this sense, aspects, in the first place, such as general interest as a student in all the staging (preparation) of class by the teacher, increased feeling that time ran faster in class, increased feeling of memorizing certain ideas and concepts more easily. In the same way, secondly, enhance the education by offering new teaching strategies; and increased perception that the teacher and the provider institution are at the forefront of techniques to teach and improve learning. All of them, can explain merely how education quality is shaped. Therefore, these current elements can be an interesting starting point to demonstrate how the quality of higher education can be measured as well [29], in this case after the implementation of SR.

Later, after conducting 106 surveys, it is proceeded to verify that there were no errors in their completion by the students who participated in the study. Thus, in this case there were no difficulties in this regard with any of the questions of the research instrument.

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3. ANALYTICAL TECHNIQUES

Once the data were collected to better understand how the use of SR impacts the improvement of classes, this article proposes a model of possible relationships, based on a methodology initially applied with ICTs on internationalized firms [30], in which the frequency of use and importance of implementation of technological resources in some specific scenarios. Statistical analysis was carried out using RStudio version 2022.02.3+492. Our primary analytical method was Spearman's correlation coefficient, employed to measure the strength and direction of associations between key variables illustrated in Figure 3. Additionally, p-values with a 95% confidence level were calculated to determine the statistical significance of the observed correlations. Thus, in this case with SR which can clearly explain the generation of academic performance in the classroom teaching process. In this manner, the alternative hypotheses under which the model was constructed and need to be accepted are set out below:

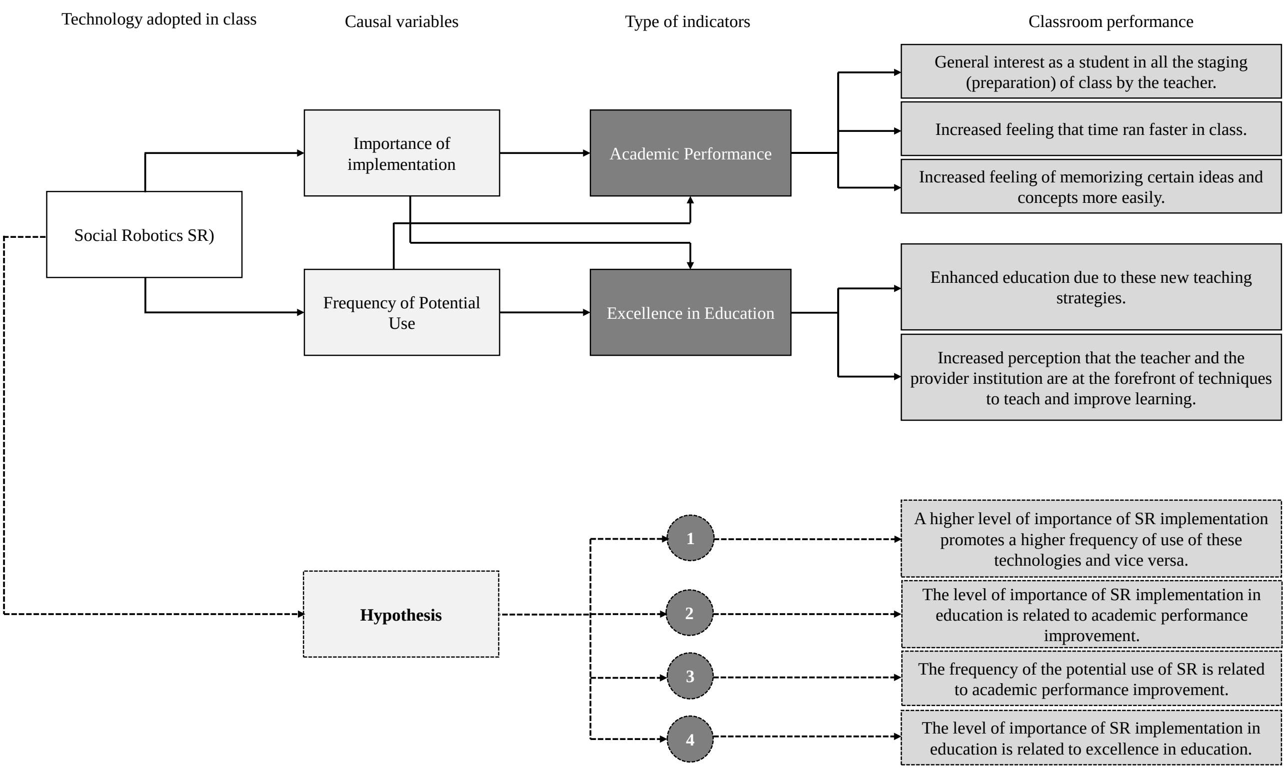

FIGURE 3. Diagram or model of possible relationships in the impact of SR on the quality of higher education classes.

III. DATA ANALYSIS

In this section of the article, a characterization of the students who participated in the survey was carried out within current study. In other words, see Table 3, aspects such as the origin of the participants were indicated, both at the university level, their country of origin as well as their level of studies and gender.

Table 3. General features of the students considered in the current study.

University	Gender	Total	%	Level of studies	Total per university	%	Country	Total per country	%
Universidad Nacional Autónoma de México	Female	49	90,74%	Undergraduate	54	51%	Mexico	74	69,81%
	Male	5	9,26%						
	Total	54	100%						
Tecnológico de Monterrey	Female	9	60%	Postgraduate	15	14,15%			
	Male	6	40%						
	Total	15	100%						

Escuela Normal Rural Lázaro Cárdenas del Río	Female	5	100%						
	Male	0	0%	Undergraduate	5	4,72%			
	Total	5	100%						
Universidad Autónoma Gabriel René Moreno	Female	12	66,67%						
	Male	6	33,33%	Postgraduate	18	16,98%	Bolivia	18	16,98%
	Total	18	100%						
Universidad de Cantabria	Female	11	84,62%						
	Male	2	15,38%	Undergraduate	13	12,26%			
	Total	13	100%				Spain	14	13,21%
Universidad Rey Juan Carlos	Female	1	100%						
	Male	0	0%	Undergraduate	1	0,94%			
	Total	1	100%						
TOTAL					106	100%		106	100%

It is worth noting that 54 students come from the Universidad Autónoma de México, in this case, equivalent to 50.94% of all participants. Similarly, 15 students from the Tecnológico de Monterrey equivalent to 14.15%; 5 students from the Escuela Normal Rural Lazaro Cárdenas del Río equivalent to 4.72%. Within the study there are also 18 students from the Universidad Autónoma Gabriel René Moreno equivalent to 16.98% 13 from the Universidad de Cantabria equivalent to 12.26%, and finally 1 student from the Universidad Rey Juan Carlos equivalent to 0.94%. All these students also come from Mexico, equivalent to 69.81%. Also 18 from Bolivia equivalent to 16.98% and 14 from Spain equivalent to 13.21% of the total respondents. Likewise, it is possible to affirm, in terms of university level, that of all 106 students surveyed in the pilot 73 are undergraduates while the remaining 33 are graduate students; that is, 68.87% and 31.13% respectively. Lastly, regarding gender in this study were consulted 87 women and 19 men equivalent to 82,08% and 17,92% respectively from 106 respondents.

Then, after describing some essential characteristics of the respondents, some correlations were successively carried out, see Figure 4 and Table 4, with the information obtained from the surveys. In this way, they explain some causal relationships that in this case start from the importance of implementation and the frequency of potential use among other circumstances associated with class performance all after adopting SR as a technological resource.

Table 4. Correlations between SR Indicators and Classroom Performance Metrics (Academic Performance and Excellence in Education) at a 95% Confidence Level.

Classroom Performance (Variable 2)	**Academic Performance**		**Excellence in Education**	
Indicator	**P-value**	**Spearman's correlation degree**	**P-value**	**Spearman's correlation degree**
Should SR be implemented to increase your attention as a student? (Academic Performance)	-	-	3.251x10-15 (Significant)	0.672 (Strong)
What is the frequency of potential use of SR to increase the quality of the education service offered by the teacher and the institution? (Excellence in Education)	3.251x10-15 (Significant)	0.672 (Strong)	-	-
General interest as a student in all the staging (preparation) of class by the teacher.	2.2x10-16 (Significant)	0.741 (Strong)	1.252x10-14 (Significant)	0.661 (Strong)
Increased feeling that time ran faster in class.	1.284x10-15 (Significant)	0.679 (Strong)	2.929x10-15 (Significant)	0.672 (Strong)
Increased feeling of memorizing certain ideas and concepts more easily.	2.506x10-13 (Significant)	0.636 (Strong)	3.439x10-16 (Significant)	0.689 (Strong)
Enhanced education due to these new teaching strategies.	9.039x10-09 (Significant)	0.523 (Moderate)	7.465-08 (Significant)	0.494 (Moderate)

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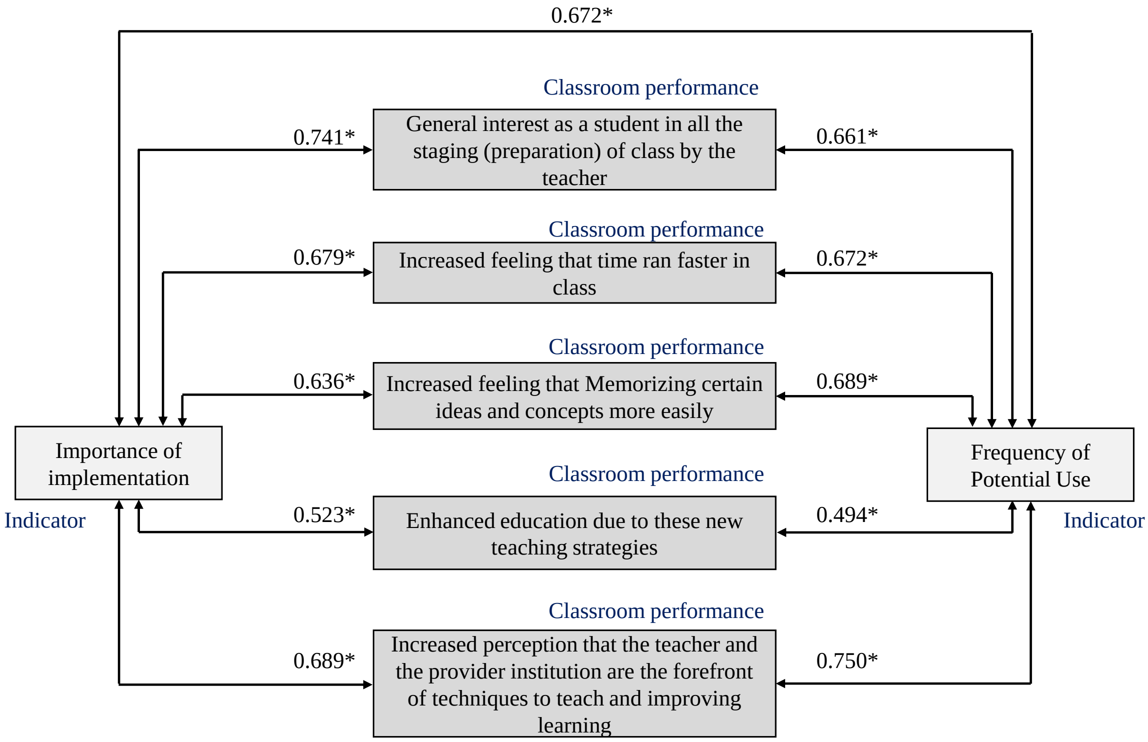
Increased perception that the teacher and the provider institution are at the forefront of techniques to teach and improve learning.	3.332x10-16 (Significant)	0.689 (Strong)	2.2x10-16 (Significant)	0.750 (Strong)



* Correlation is significant at the P-value ≤ 0.05 level (two-tailed) (95% confidence level)

FIGURE 4. Correlations between the level of importance of SR implementation and frequency of potential use of SR with the classroom performance.

In this way, statistical analysis was performed using RStudio 2022.02.3+492 and Spearman's correlation coefficient was used to measure the strength and direction of the association between the variables presented in Figure 3. Two ranked variables were analyzed, first the importance of implementation with the frequency of potential use. Following is the importance of implementation with classroom performance. Ending with the frequency of potential use with classroom performance. Finally, the P-value with a 95% confidence level was analyzed to obtain which variables were statistically significant.

Thus, Figure 4 depicts correlations and P-value for the indicators and the classroom performance described in Figure 3. Besides, Table 4 shows the correlations between the indicators and the classroom performance at a 95% confidence level, thus any P-value less than or equal to 0.05 is significant. This table shows that there are significant positive correlations between the indicators and between the indicators with classroom performance. Besides, in all the correlations, except for the enhanced education, Spearman's correlation degree is strong. In the case of enhanced education is moderate for both indicators. Therefore, this table accepts the four alternative hypotheses stated in the previous section.

Subsequently, in the following section of the results, a representation of those elements that can be analyzed among the students and that effectively explain whether a class mediated with SR generates positive perceptions was carried out. All these which can also favor higher education in terms of quality.

Figure 5 shows the Likert responses bar from the indicators and the classroom performance variables. The respondents considered that enhanced education is very important (57%). The variables with a higher percentage of "not important" answers were the Excellence in Education indicator and the increased feeling that time ran faster in class with 7%. Moreover, the variable about the feeling of memorizing certain ideas and concepts had 25% of "neutral" answers and 25% of "very important" answers. Thus, ¼ of the respondents did not have a clear idea if the SR can increase their memory.

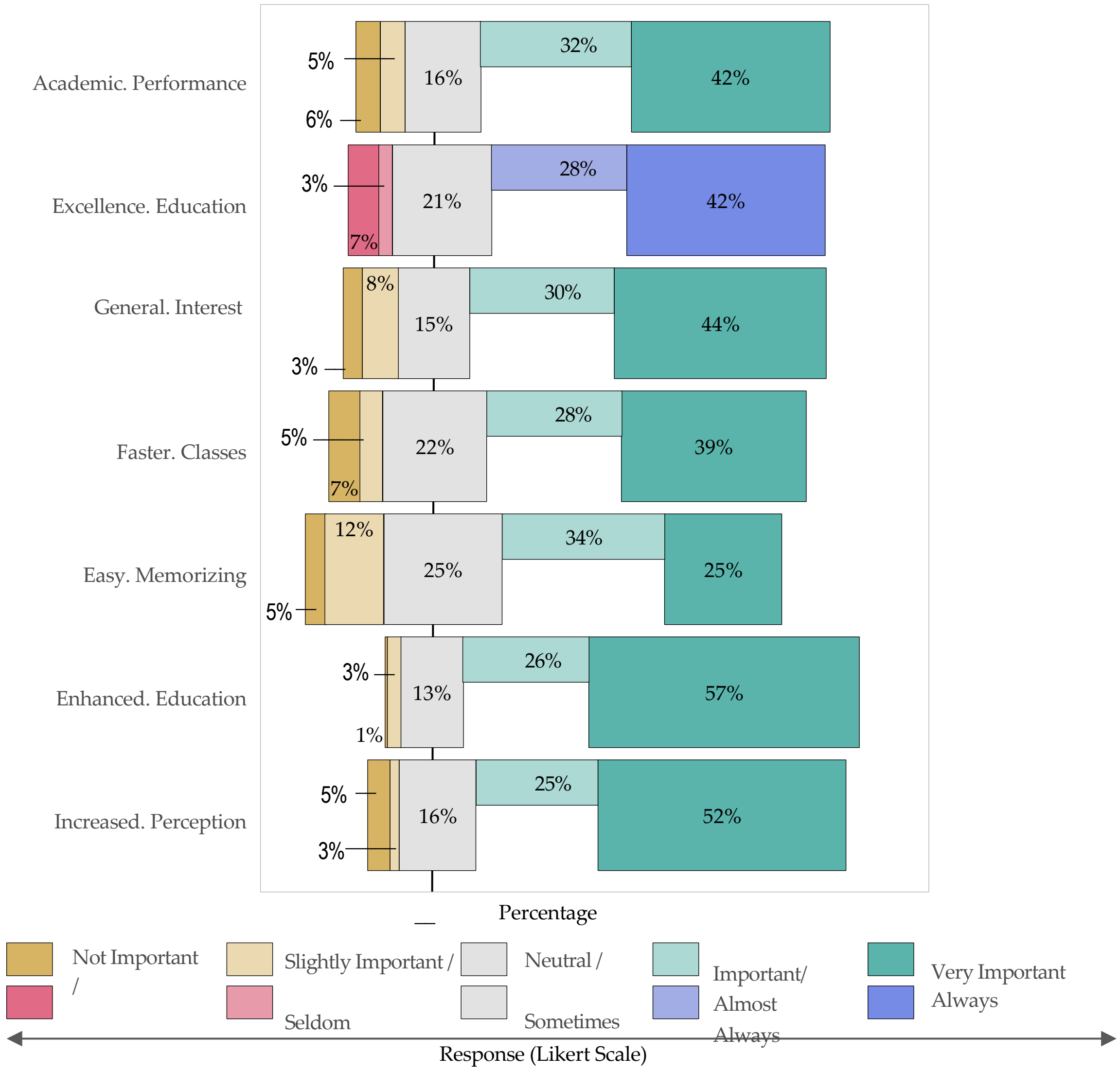


FIGURE 5. Likert response for the Indicators and the Classroom Performance variables.

In this last part of the results, it is possible to recognize some additional perceptions among students regarding the implementation of SR in higher education classes. Therefore, in Figure 6, these technological tools evidently enhance the class sessions in scientific research, clearly favoring the entire teaching process.

Based on all of the above, Figure 6 shows some quite striking positive perceptions that also reinforce the previous correlations regarding the implementation of SR in the classroom. In this way, regarding the first perception, 80 students equivalent to 75.47% consider that "Lessons become less boring". In the second, 70 students equivalent to 66.04% consider that "the communication is appropriate despite the interventions of the assistant robot". In the third, 66 students equivalent to 62.26% believe that "the fluency of the robot and the teacher is ideal". In the fourth, 82 students equivalent to 77.36% believe that "The robot is at least attractive when transmitting information together with the teacher". In the fifth and last perception, 78 students equivalent to 73.58% consider that "The interaction of the robots is suitable for a rigorous and entertaining class". Therefore, in all the cases analyzed, at least more than two thirds of the respondents consider RH as attractive for the improvement of higher education classes.

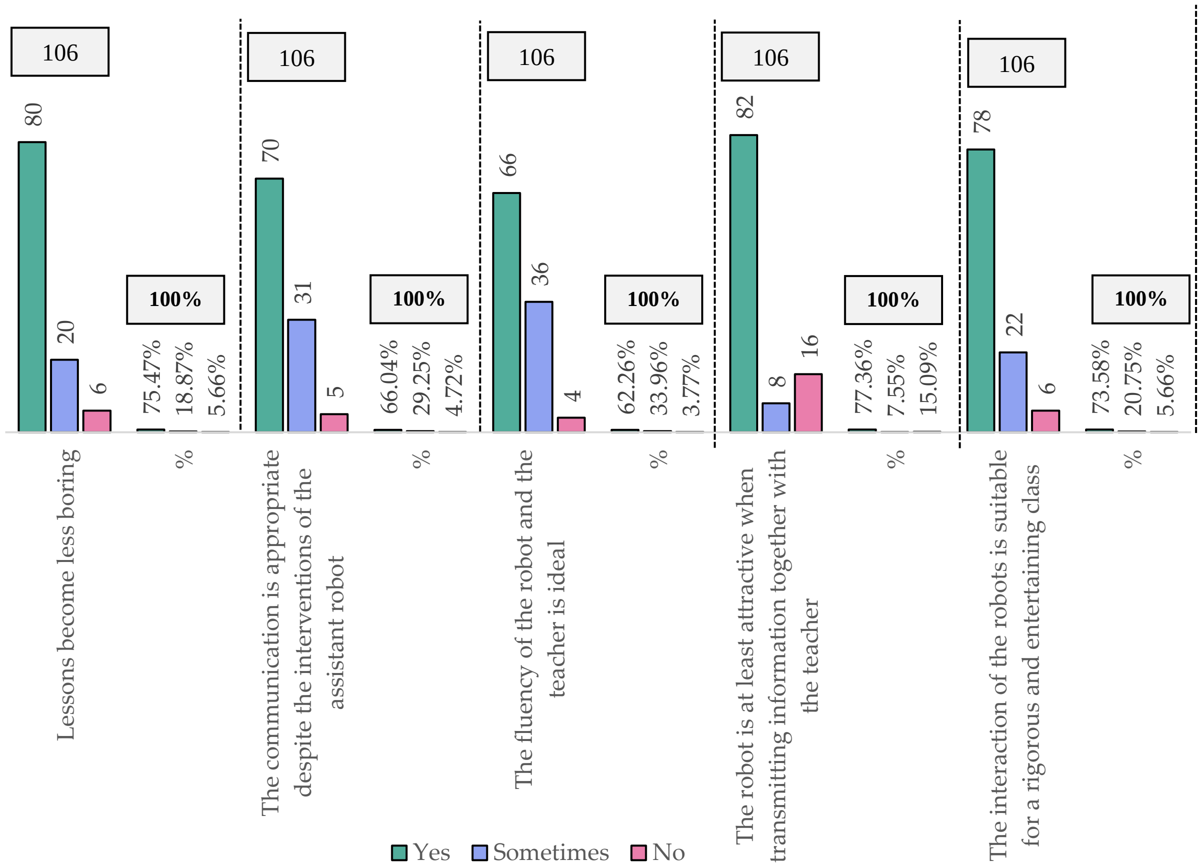


FIGURE 6. Perception of SR as technological tool adopted in classroom within the teaching process

IV. DISCUSSION

Technological resources significantly improve the quality of life and enhance educational experiences. In the educational sector, these tools foster better problem-solving skills and adaptability to new learning trends, thereby enhancing team cooperation and fostering a learning community within the classroom [31–34]. Our findings support the notion that technologies, particularly SR, effectively enhance classroom performance. This is manifested in aspects like general interest, quicker class progression, and enhanced memorization abilities

In this sense, it is necessary carry out a conceptual model with complex thinking as disruptive construct which is based on developing specific skills and/or cognitive processes for problem solving and boosting, as well different competencies which prepare students and professionals for the future where the proliferation of uncertainty and new technologies will be a constant within any society [35].

The empirical evidence from the pilot study applied across Ibero-American universities confirms the effectiveness of these technologies. For example, 42% of respondents identified SR as 'Very Important' for both academic performance and excellence in education, suggesting that SR not only supports but significantly enhances the educational process.

Additionally, positive feedback on SR's impact on 'General Interest' and 'Faster Classes' (44% and 39% respectively finding it 'Very Important') reinforces SR's role in making educational sessions more engaging and efficient. This aligns with previous research by Guggemos et al. [14] and Rosenberg-Kima et al. [15], who demonstrated that SR could significantly improve engagement and collaborative learning.

However, the variability in responses, especially regarding 'Easy Memorizing', where 25% were neutral, indicates that SR's effectiveness can vary based on specific educational contexts and individual student needs [35]. This highlights the necessity for adaptive learning systems within SR technology to cater to diverse learning styles and preferences.

Moreover, the strong positive responses to 'Enhanced Education' and 'Increased Perception' (57% and 52% finding it 'Very Important', respectively) underscore the significant role of SR in shaping modern educational paradigms. These findings not only reinforce the acceptance of SR as a beneficial educational tool but also illustrate its potential in elevating the perceived quality and modernity of educational institutions [36–38].

Thus, considering all the previous ideas, the entire present study, derived from the pilot applied among Ibero-American universities, corroborates how technological resources and multimedia devices favor learning among higher education students. In this case, according to empirical evidence, SR shows an incidence between classroom performance and other aspects such as general interest as a student in all the staging (preparation) of class by the teacher, increased feeling that time ran faster in class, increased feeling of memorizing certain ideas and concepts more easily and others. In other words, there are significant correlations between all the elements proposed in the model of this article, which makes it clear that the implementation and frequency of use of social SR as a technological resource has an impact on improving online classes and therefore higher education. Likewise, it can be said that the hypotheses proposed throughout this study are validated with the data collected with the survey applied among the students.

It is necessary to add that the notion of quality in higher education has to do with a series of positive perceptions of the students who participate in a class. Then, the sensations of comfort, pleasure, good communication, desire to participate among many other aspects, can be essential starting points to conceive the level of quality of the classes [36–38]. In this specific case, the evidence indicates that most students experienced a positive sensation that validates the potential use of this technological resource that is increasingly adopted by some higher education institutions. In addition, the pilot showed that at least two thirds of the respondents were enthusiastic and satisfied with the classes measured with RS. This is because the students did not feel bored, the communication was adequate, they noticed synergy between the robot and the professor, the experience of transmitting information was attractive, and the class was entertaining and rigorous.

Furthermore, the current situation is corroborated by the findings of other studies that highlight how adopting SR and robotic tutoring is beneficial to students because it generates significant subjective knowledge gains as well as increases in intrinsic motivation with respect to the overall course content. In other words, students perceived the robot positively, as friendly and responsive; therefore, these findings suggest that the complementary features of the robot allow for a higher quality learning environment with robot-mediated collaborative learning which may represent a promising new paradigm for higher education [15, 16].

In this sense, SR may become in the future one more technological tool or resource that will tend to become normalized over time, as has happened with other tools, such as ICTs. Partly because students and educational systems normalize them with their acceptance, which derives from the way these actors feel when they are implemented in classroom sessions.

Last but not least, it is necessary to highlight that some technologies or tools such as the ones implemented in this field study; are not, at least for now, easy to include in a classroom.

This is because, for example, social robotics demands considerable budgets to be able to acquire this type of tool that is usually expensive at present; all this, given its level of specialty. Similarly, the programming of robots requires training for teachers, not only for the creation of scripts, but particularly to program them when participating in class. It is for all this that at present it would be ideal to have at least one support member to help the teacher with the use of the tool while improving the "perceived usefulness" and "perceived ease of use" of the tool according to the technology acceptance model (TAM) theory.

1. LIMITATIONS

This study, while providing insights into the use of SR in educational settings, has several limitations that suggest areas for future research. The sample was confined to Ibero-American universities, which may not fully represent broader educational contexts, highlighting the need for studies that include a more diverse and extensive range of institutions to enhance generalizability. Moreover, the integration of SR with other educational technologies requires further exploration, suggesting that future work could examine how SR can be synergistically combined with existing digital tools to maximize educational outcomes. The research presented a snapshot based on a single pilot implementation, thereby necessitating longitudinal studies to assess the sustained impact of SR, especially on student engagement and academic performance over time. Another limitation, like previous research, is the high cost and resource demands associated with SR, which restricts wider adoption. This is compounded by challenges in teacher training and acceptance, which are critical for the effective deployment of SR. Future studies should therefore explore cost-effective, scalable models for SR and examine the effects of comprehensive teacher training programs on the successful integration of SR. Lastly, the research predominantly employed quantitative methods; incorporating qualitative methodologies could provide a richer understanding of the subjective experiences of both students and teachers, further elucidating the qualitative benefits and challenges of SR in educational settings.

V. CONCLUSION

The study included a diverse group of participants from different universities and countries. Half of the students came from the Universidad Autónoma de México. Other students were from Tecnológico de Monterrey, Escuela Normal Rural Lazaro Cárdenas del Río, Universidad Autónoma Gabriel René Moreno, Universidad de Cantabria, and Universidad Rey Juan Carlos. The participants were predominantly from Mexico, followed by Bolivia and Spain.

Key findings indicate that most students recognize the importance of SR in enhancing educational experiences. Notably, while the indicators for excellence in education and the perception of time speeding up during classes received mixed reviews, the majority affirmed the positive impact of SR on making lessons more engaging and interactive. This suggests that SR not only enhances the delivery but also the reception of educational content.

However, responses varied concerning SR's impact on memorization, indicating an area for further investigation and potential optimization of SR applications to better support cognitive processes in learning environments.

The ICTs was highlighted as critical in supporting SR, particularly in facilitating remote learning. Tools like email, video chat, and collaborative software were identified as instrumental in ensuring the continuity and quality of education, underscoring the strategic role of technology in fostering effective communication and collaborative learning.

Moreover, the study underscored the importance of engaging students in scientific research, fostering critical and innovative thinking skills necessary for academic and professional success. The pilot study emphasized that active participation in research and academic projects via SR enhances students' abilities to engage critically with content, propose innovative research methodologies, and appreciate interdisciplinary approaches.

Thus, some of the recommendations for educators are to enhance engagement to make learning more interactive, using robots not just as teaching aids but as integral elements of the learning process that can respond dynamically to students needs. Given the varying opinions on the effectiveness of SR in enhancing memorization, institutions should consider specialized training for educators to optimize the use of SR in ways that support cognitive functions and learning retention. Schools and universities should continue to integrate ICTs alongside SR to create an educational framework that supports both in-person and remote learning, ensuring that all students have access to high-quality education regardless of their physical location. Encourage the use of SR in research-oriented activities to help students develop essential skills such as critical thinking and problem identification, ensuring that they are well-prepared to tackle complex, real-world problems. Tailor SR applications to accommodate diverse learning styles and cultural contexts, ensuring that the technology is as effective in one educational setting as it is in another.

This research revealed some future work to further explore the potential of technological resources, including SR and ICTs, in promoting complex thinking and meta-competencies in students. Thus, by conducting longitudinal studies and examining the long-term impact of SR implementation, researchers can assess the sustainability and scalability of these interventions.

Consequently, future research explores the role of content-sharing platforms, tailored classes, online discussion forums, and other collaborative tools in fostering a sense of learning community and supporting problem-based learning. Understanding the dynamics of these interactions and their impact on learning outcomes can provide valuable insights into the educational field.

Hence, by conducting comparative studies across different educational contexts to explore the variations in students' perceptions and experiences of SR implementation in diverse cultural and educational settings. Comparing the effectiveness of SR in other subject areas and disciplines can also shed light on its applicability across various academic domains.

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Author contribution

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data are available from the authors upon request.

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