methaodos.revista de ciencias sociales (2023) 11(2) m231102a12

Interpersonal Communication in Virtual Laboratories during the pandemic: a systematic literature review

Comunicación Interpersonal en Laboratorios Virtuales durante la pandemia: un análisis sistemático de la literatura

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10.17502/mrcs.v11i2.704

Received: 31-05-2023
Accepted: 20-09-2023

Abstract

Interpersonal communication is crucial in education for developing lifelong problem-solving skills. Despite its decline during the pandemic, research in virtual educational environments, such as Virtual Laboratories, remains limited. On the other hand, the pandemic has stimulated exploration and development of these tools. The objective of this article is to identify problematic situations in Virtual Laboratories to enhance interpersonal communication. Employing a Systematic Literature Review method encompassing articles published between 2019 and 2022, our study yields the following key findings: a) Interpersonal communication remains undercovered in main focus; b) Technical and natural disciplines dominate in Virtual Laboratories; c) The research on interpersonal communication is insufficiently addressed in main objectives and results; d) Interpersonal communication is valued for various pedagogical reasons, with its relevance in collaborative learning standing out; e) The concept of Virtual Laboratory adopted by researchers may guide the way the importance of interpersonal communication is seen. This research will benefit the innovation process in the context of Virtual Laboratories in need to develop the competencies of global importance.

Keywords: interpersonal communication, global competencies, Virtual Laboratory, pandemic, educational innovation.

Resumen

La comunicación interpersonal es crucial en la educación para desarrollar habilidades de resolución de problemas a lo largo de la vida. A pesar de su disminución durante la pandemia, la investigación en entornos educativos virtuales, como los Laboratorios Virtuales, sigue siendo limitada. Por otro lado, la pandemia ha estimulado la exploración y desarrollo de estas herramientas. El objetivo de este artículo es identificar situaciones problemáticas en los Laboratorios Virtuales para mejorar la comunicación interpersonal. Mediante un método de Revisión Sistemática de la Literatura que abarca artículos publicados entre 2019 y 2022, nuestro estudio arroja las siguientes hallazgos clave: a) La comunicación interpersonal sigue siendo insuficientemente abordada como foco principal; b) Las disciplinas técnicas y naturales predominan en los Laboratorios Virtuales; c) La investigación sobre la comunicación interpersonal se aborda de manera insuficiente en los objetivos y resultados principales; d) La comunicación interpersonal es valorada por diversas razones pedagógicas, destacándose su relevancia en el aprendizaje colaborativo; e) El concepto de Laboratorio Virtual adoptado por los investigadores puede influir en la percepción de la importancia de la comunicación interpersonal. Esta investigación beneficiará el proceso de innovación en el contexto de los Laboratorios Virtuales, necesario para desarrollar competencias de importancia global.

Palabras clave: *comunicación interpersonal, competencias globales, Laboratorio Virtual, pandemia, innovación educativa.*

Summary

How to cite this work

Artemova, I., Ulloa Carzarez, R. L., & Chávez-Aguayo, M. (2023). Interpersonal Communication in Virtual Laboratories: a systematic literature review. *methaodos.revista de ciencias sociales, 11*(2), m231102a12. https://doi.org/10.17502/mrcs.v11i2.704

1. Introduction

Numerous frameworks at international level refer to the interpersonal communication skills as some of the most important for professional and personal development. The United Nations Children's Fund (UNICEF) places this competency in a group of social competencies, along with cognitive and emotional competencies, which altogether define the success in school, life and work (UNICEF, 2017). The Organisation for Economic Co-operation and Development (OECD) considers communication and negotiation skills as essential elements to understand the functioning of adult learning systems within social and negotiation skills (Kirsch & Lennon, 2017).

Communicative and collaborative competencies are also essential for citizens to be effective (Battelle for Kids, n.d.; Carretero *et al.*, 2017) in confronting and solving complex problems and in managing complex working environments. Considering the scope of importance of the communication competency, The United Nations Educational, Scientific and Cultural Organization (UNESCO) highlights its place within an educational framework for the year 2030 as a transferable skill for life that should facilitate the adaptation of the graduates to rapid changes in the labor market (UNESCO, 2016). Preparation of future citizens in these competencies starts at first stages of education (García Gómez y Carmona Fernández, 2014).

In recent years, and especially because of the pandemic impact and closing of physical schools at all levels, educational systems all over the world suffered forced transition to virtual environments and incorporation of digital tools for asynchronous and distance learning (Bozkurt & Sharma, 2020). These transitions had positive as well as negative effects on all educational levels (Greere, 2021; García Aretio, 2021). Given the rapidness of this transformation and the irreversibility of this process (Naffi, 2020), the question that emerges is how the assessment of the competencies, and the communicative competency in particular, should be addressed in this digital context.

The questions of addressing globally desired competencies and incorporation of technological tools in wide educational contexts corresponds to the educational innovation processes (Fuad *et al.*, 2022) needed for enhancing the efficiency, productivity, and competitiveness of educational institutions (Manafi & Subramaniam, 2015). In the context of education, a number of actions are considered to boost innovation in this area: to restrict and refine the extent of the innovation, to identify challenging problematic situations, examine their contexts, and carefully evaluate the modifications (Valenzuela, 2017).

Virtual Laboratories in education have been known for some decades (Lei *et al.*, 2022). However, the focus of research on these tools was mainly linked to their design, development, and usage in higher education (Raman *et al.*, 2022).

The requirements of pandemic educational closure had an impulse on creating and testing more of these tools (Schnieder *et al.*, 2022). Virtual Laboratories are usually defined as software-based "online learning media" (Erdem *et al.*, 2016, p. 452) that makes a student feel like "working with real authentic devices in a real authentic space" (Potkonjak *et al.*, 2016, p. 311). These learning environments allow visual interaction with the objects (Senapati, 2022), can be used to analyze data, model processes (Hardisty *et al.*, 2016) and serve consolidating knowledge in practice (Gubsky *et al.*, 2022). These spaces also allow saving time and money and are highly accessible (Makransky *et al.*, 2019) for the students with different profiles. They can be used for teaching any discipline, and be applied to "any studies, course or training programme" (Dobrzański & Honysz, 2010, p. 196).

Virtual Laboratories as digital technologies share a main advantage: they are tools particularly supportive for informal and lifelong learning (Yin & Shi, 2022). This allows the adaptation of these virtual environments for the needs of a variety of educational contexts: formal or inside of a compulsory educational system, informal or cooperative learning with friends or family members in spontaneous life situations (Eshach, 2007), and non-formal, such as workshops, seminars and trainings at working space (Kicherova & Efimova, 2020), the latest are carried out in institutionalized settings — e.g., libraries or museums — but situated outside the school (Moldovan & Bocoş-Binţinţan, 2015). Introduction of tools like Virtual Laboratories can break the boundaries of formal education (Martín-Gutiérrez & González-Marrero, 2017).

Given all these distinctive features of a Virtual Laboratory, this tool undoubtedly contributes to reaching Sustainable Development Goals in Education (SDG4) (UNESCO, 2021) and thus will remain in the focus of educational research all over the world in post pandemic times.

The shutdown of educational facilities due to the pandemic, which resulted in a switch to online education, demonstrated the importance of interpersonal communication not only for knowledge outcomes, but also for students' and teachers' relations and their psychological state in general (UNESCO, 2020). Pandemic times

led to degradation of abilities in personal communication (Kaputa *et al.,* 2022), and it is important to address this issue in light of the further digitalization of education at all levels and in each specific context of it.

In this article, the focus of interest is on Virtual Laboratories and the possibilities of interpersonal communication that allow interactions with teachers and peers. Given that research before pandemic addressed issues related to interpersonal communication in physical settings, leaving virtual environments undercovered (Lundberg & Sheridan, 2015; Redmond *et al.*, 2018), and considering the exacerbation and obviousness of this problem in pandemic times, the aim of this work is to find out how researchers addressed interpersonal communication issues within studies dedicated to Virtual Laboratories in education during pandemic closure.

It is of a particular interest to validate if interpersonal communication appeared as the main focus of research during these times, to identify within which educational contexts was research carried out, and what disciplines were related to. These issues are in the center of the present research due to contextual specifics of communication needs within each context and discipline. So as to say, learning physics may demand different communication possibilities than learning within humanities. The same applies to educational contexts: undergraduate students may have different necessities than postgraduate students. The technical aspect of providing these interactions is in the scope of the present research. Assuming that in some cases interpersonal communication may not be the main focus of such articles, it is proposed to analyze main objectives and results of these works in its relation to interpersonal communication issues. It is also in the scope of the present study to identify how the selected works generally address interpersonal communication, if it is seen as of importance or not, and to recover the reasons for these standpoints.

Interpersonal communication with peers and teachers plays a necessary role in the process of knowledge construction which, according to Vygotsky, is a result of interactions in certain social and cultural settings (Schreiber & Valle, 2013). Social constructivism methods play a critical role in achieving learning outcomes and fall basically into two groups: discussion and small group work. Discussion promotes the cultivation of critical thinking, the enhancement of research capabilities, and the ability to assess and analyze the perspectives of others, whereas working in a small group emphasizes the learners' reflection and reasoning abilities in order to construct their own learning experiences (Akpan *et al.,* 2020).

The communication dynamics in virtual spaces differs from the dynamics on in-person classrooms: communication becomes extended, and in the case of a Virtual Laboratory the psychomotor dimension is replaced by the visual interactions and data visualization. Social interactions and relationships established in this type of educational context impact the process of learning and knowledge acquisition. It is crucial to examine the variations in the nature and channels of discussion and small group work within different virtual educational contexts, as well as the potential transformations these two forms of interpersonal communication may undergo in each specific virtual educational setting. To begin this exploration, it is necessary to investigate the interaction challenges within the settings of a specific context.

Moreover, the social dimension of learning is interconnected with other dimensions, like cognitive, affective, psychomotor, and metacognitive dimensions (Sawyer, 2005). These dimensions may have different levels of activation depending on the construction of a virtual environment as a social and cultural space. For this reason the importance and a concept of interpersonal competency may be perceived differently by researchers. Therefore, this article aims to examine the construct of a Virtual Laboratory based on selected research, recognizing that virtual learning environments are social spaces tailored to the communication needs of students and teachers, that shape students' cognitive development and learning outcomes.

The goal of this article is to contribute to the field of digital transformations in education, by focusing on a Virtual Laboratory as an emerging virtual space for collaboration; in this quest, the article centers on the enhancement of interpersonal communication by identifying problematic situations associated with this subject.

Given the base of this research, the following research questions (*RQs*) were posed:

RQ1. What is the main focus of the articles related to Virtual Laboratories and considering interpersonal communication?

RQ2. What educational contexts and disciplines do these articles address?

RQ3. Do interpersonal communication issues appear in the main objectives and results of the articles? If not reported in main results, are issues concerning interpersonal communication reported in additional results?

RQ4. What are the results concerning interpersonal communication that are either reported as main or additional results?

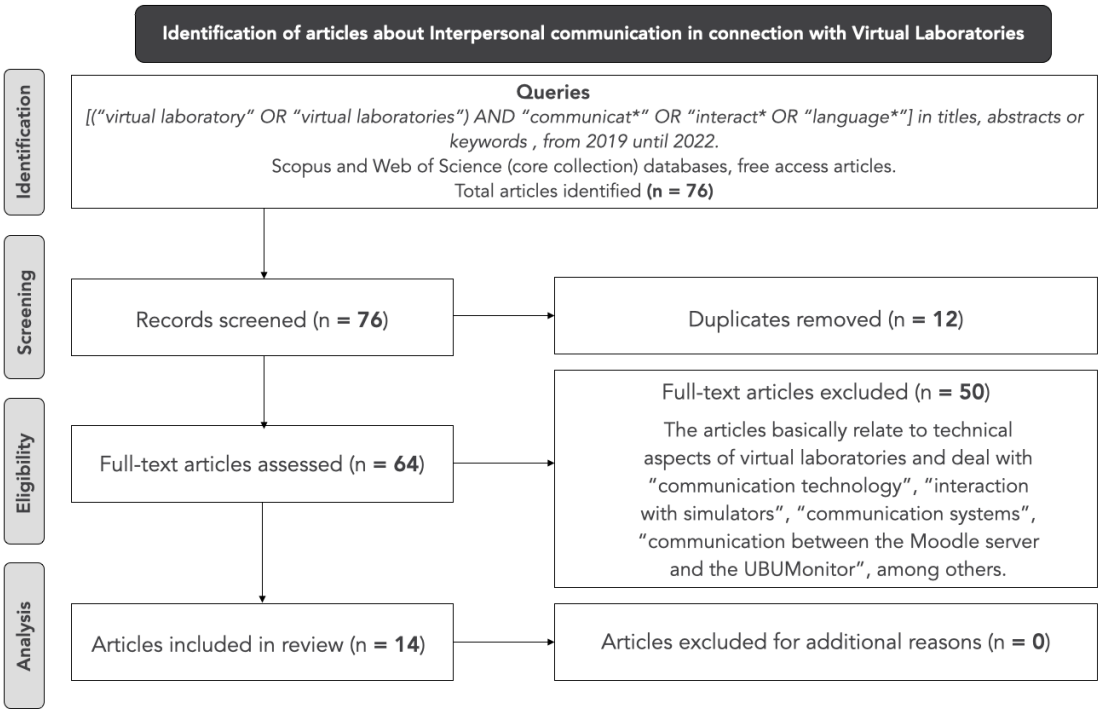
RQ5. In the entire corpus of selected articles, and within their full texts, with which topics is interpersonal communication associated?

RQ6. What is a Virtual Laboratory in the articles that address different issues related to interpersonal communication?

2. Methodology

A Systematic Literature Review (SLR) was conducted based on the PRISMA method (Moher *et al.*, 2009; Ciapponi, 2021), which was applied in its four phases: Identification, Screening, Eligibility and Analysis report on the included articles. To support the PRISMA method, the thematic analysis was applied, identifying themes, which emerged while searching for information in relation to interpersonal communication (Cohen *et al.*, 2018, p. 644). In particular, thematic analysis was applied to answer the questions about the main focus of the articles, educational context and disciplines, results achieved, the stance adopted by the authors towards interpersonal communication and the understanding of the concept of Virtual Laboratories. Figure 1 illustrates PRISMA's methodological steps for identifying articles on interpersonal communication in Virtual Laboratory settings.

Figure 1. Flow of methodological PRISMA steps



Source. Own elaboration.

In the phase of Identification, the search was conducted in the Scopus and Web of Science (core collection) databases, for the reason that both databases include high quality literature, which undergoes rigorous reviews. The search query included [("virtual laboratory" OR "virtual laboratories") AND "communicat*" OR "interact* OR "language*"] for titles, abstracts, or keywords and bounded to years from 2019 until 2022, which cover the pandemic period. For both databases, it was decided to restrict the search to articles, since these scientific products typically require less time for publication and offer a structured format, including sections such as the theoretical framework, methodology, results, and conclusions. It was also decided to restrict the analysis to texts with free access. In this phase, 76 articles were identified.

In the Screening phase, 12 duplicates were removed from the database. Then, in the Eligibility phase, 50 articles were excluded after the extensive reading of the texts and analysis of its relevance to other issues of interpersonal communication, leaving a total of 14 articles. The excluded articles were related basically to technical aspects of Virtual Laboratories and dealt with "communication technology"; "interaction between cognitive style-gender within (Virtual Laboratory)"; "interaction between devices"; "interactive learning games"; "interaction with simulators"; "communication systems"; "communication between the Moodle server and the UBUMonitor"; "interactive environment", among others. In this phase, they resulted in a total of 14 articles to be included into the phase of Analysis related to issues of interpersonal communication. The full texts of the selected articles are in English, Spanish, and Russian, all of which are languages within the competencies of the authors of this research. All 14 articles were analyzed with a method of thematic analysis to answer the proposed research questions and no more articles were excluded for any other reasons (see Table 1 in Appendix).

As for full-text articles, excluded at the stage of Eligibility, these appear to focus primarily on the development, implementation, and benefits of Virtual Laboratories in various educational contexts. They explore the interactive and immersive aspects of these tools, their potential to enhance students' learning experiences, and their effectiveness in teaching a wide range of subjects, from chemistry to engineering. While these articles explore the advantages of Virtual Laboratories, they do not delve into the topic of interpersonal communication, such as interaction dynamics, or challenges faced in virtual learning environments. Therefore, these articles were considered as not suitable for studying problematic situations in connection with interpersonal communication.

3. Results

In this section, the results corresponding to the research questions are reported. First, the results related to the main focus are presented: educational context and discipline of the articles, related to the aspects of interpersonal communication.

RQ1. What is the main focus of the articles related to Virtual Laboratories and considering interpersonal communication?

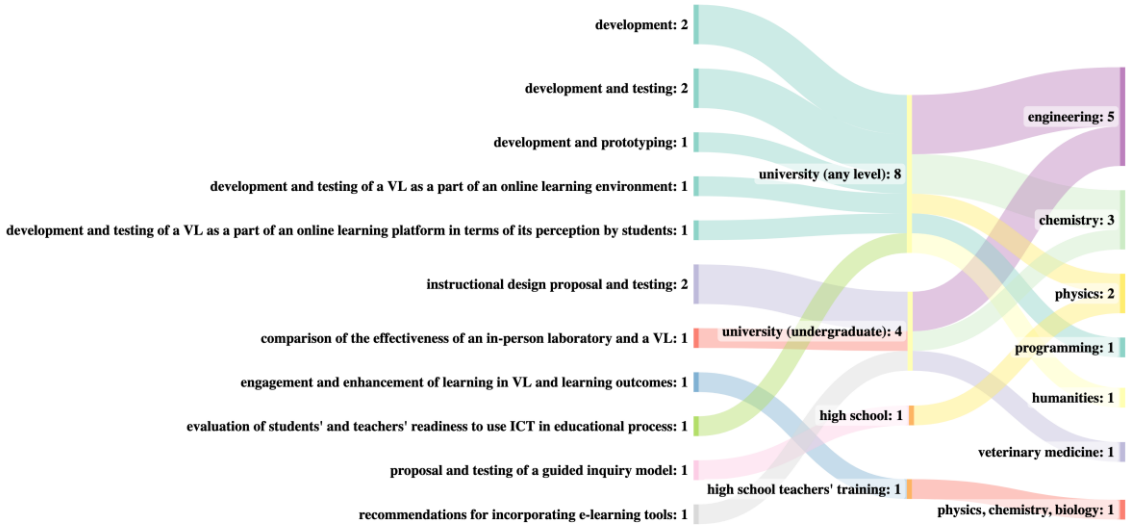
As for the focus of the analyzed articles, half of them (seven articles) are dedicated to the development of a Virtual Laboratory with a profound technical background. Only two articles are dedicated merely to technical aspects of the process for building a Virtual Laboratory, others are supported by testing it with users (four), of which two consider a broader context for a Virtual Laboratory: an online virtual environment and an online platform. One article is focused on students' perception of the use of Virtual Laboratories, rather than the effectiveness of its use for learning outcomes. One article is focused on Virtual Laboratory development and its prototyping.

Seven articles are dedicated to different aspects of managing a Virtual Laboratory from a pedagogical perspective: two focus on instructional design in a Virtual Laboratory and testing a proposal with students; one is dedicated to the comparison of the effectiveness of learning in an in-person laboratory and a Virtual Laboratory; one article is focused on the aspects of engagement and learning enhancement in a Virtual Laboratory and its learning outcomes; one article is dedicated to the evaluation of students' and teachers' readiness to use different ICTs, including Virtual Laboratories; one article is dedicated to the proposal and a test of a guided inquiry model; and one article is dedicated to recommendations for incorporating different e-learning tools, including Virtual Laboratories, into the educational process.

RQ2. What educational contexts and disciplines do these articles address?

As for the educational context, most of the articles address the topic of Virtual Laboratories and interpersonal communication in relation to any university level (eight articles). Four articles focus particularly on undergraduate university level, one on high school and one article reports the results obtained during high school teachers' training. As for the disciplines, five articles are related with engineering specialties, three with chemistry, two with physics, one with programming, one with humanities, one with veterinary medicine and one focused on physics, chemistry and biology at once. The results of the analysis that supports *RQ1* and *RQ2* are presented in Figure 2.

Figure 2. Sankey diagram: main focus, educational context and disciplines



Source. Own elaboration.

To support the results obtained in relation to the main focus of the articles, and the importance of topics as it is seen by the authors of the selected articles, an analysis of author keywords was performed, which integrates a total of 167 keywords from all the 14 articles, and is presented in an alphabetical order with each word frequency as a word cloud in Figure 3.

The analysis clearly shows that learning goals and outcomes are prevalent in the articles concerning interpersonal communication in the settings of a Virtual Laboratory, with undergraduate level being mostly recognized in the general field of education. Authors employ a diverse array of technical and natural science disciplines, along with specific terms, to emphasize their work in relation to subtopics such as chemical, chemistry, computing, engineering, heat, industry, mechanics, medicine, science, software, solids, spectroscopy, system, and veterinary. Additionally, it's noteworthy that communication is not recognized as the primary focus in all of the selected articles; the authors have chosen it as a keyword only three times.

RQ3. Do interpersonal communication issues appear in the main objectives and results of the articles? If not reported in main results, are issues concerning interpersonal communication reported in additional results?

In Table 2 (see Appendix), outcomes concerning main objectives, main and additional results in relation to interpersonal communication are reported.

As for the main objectives, only two articles address the issue of interpersonal communication directly (articles 4 and 10): one investigates the development of this competency while using different digital communicative tools and the influence of this process on personal relationships, and another one investigates

the development of this competency in the instructional model for developing inquiry skills. The first article keeps its focus on introducing an online learning environment.

Figure 3. Author keywords frequency analysis

Source. Own elaboration.

Other articles take in their main objectives the development of a virtual environment or ecosystem with certain characteristics or for comparing students' perceptions of using a Virtual Laboratory (articles 1, 6 and 8); to investigate the impact of the usage of a Virtual Laboratory on learning outcomes (articles 3, 7, 9 and 13); to propose theoretical background for incorporating digital resources for extension of a learning environment (articles 2 and 14); to test a Virtual Laboratory prototype (article 12); to evaluate instructional design proposal (article 5); and to measure the readiness of teachers and students for adoption of digital educational tools (article 11).

In some cases, the main focus of the article coincides with a main objective, but in most of the cases the objectives are more concrete.

A total of 7 articles reported issues related to interpersonal communication in the main results (articles 4, 6, 10, 11, 12, 13 and 14), while 6 articles reported the results related to interpersonal communication as additional (articles 1, 2, 3, 5, 7 and 8). And one article did not report interpersonal communication in the main objectives or results of the research (article 9), and only refers to it in Limitations.

As seen from Table 2, the articles that report communication processes in main results generally do not address interactive human processes directly in their objectives. Despite this, these articles suggest resolving issues related to communication within a more general topic. For example, "to investigate the impact of implementing the guided inquiry model using a Virtual Laboratory on students' science process skill" (article 13 in Table 2).

RQ4. What are the results concerning interpersonal communication that are either reported as main or additional results?

Five of the articles that report issues concerning interpersonal communication in the main results state that the created system or model fosters personal interactions effectively (articles 4, 6, 10, 12, 13), two articles address the necessity to foster it, as these have an observational focus (article 11) and a format of a proposal (article 14). Articles that address communication in additional results mention simple forms of communication like chatbots and Microsoft Teams as effective to support interpersonal communication (articles 1, 5); refer to this topic as a necessary to work on (article 2); report created environment as effective to support interpersonal interactions (article 3); talk about the necessity to support synchronous interpersonal communication (article 7), and highlights the benefits for interpersonal communication that the proposed environment does not

have (article 8). Article 9, in the part of Limitations, emphasizes that Virtual Laboratory learning may encourage decline in teamwork and communication between tutors and students.

The additional results also indicate that it is crucial to consider the possibilities for interpersonal communication in the process of development of Virtual Laboratories, being the only place for the interaction or extended to a broader virtual environment. The reason is that these interactions improve learning outcomes. The results also indicate that for some students the remote ways of interpersonal communication may contribute to their confidence for learning while asking as many questions as possible and express the doubts that they may not be expressing in front of their peers due to the personal traits of their personality, like shyness. The instructional design for using a Virtual Laboratory should consider interpersonal communication, between students and teachers, to improve learning outcomes. Also, the researchers consider that more emphasis should be given to improving interaction in e-learning environments.

In general, the results concerning the necessity of interpersonal communication are contradictory: some researchers report that the students who study remotely may have more questions on the theory, experimental procedures and processes, others report that very few students expressed the necessity for interpersonal interaction.

RQ5. In the entire corpus of selected articles, and within their full texts, with which topics is interpersonal communication associated?

As for the ways the selected articles address interpersonal communication, the results of this analysis are presented in Figure 4 and is a result of the thematic analysis of representation of issues concerning interpersonal communication in selected articles.

Figure 4. Representation of the topics in relation to interpersonal communication in articles concerning Virtual Laboratories

Source. Own elaboration.

Most articles present interpersonal communication as important for the influence of collaborative learning in knowledge construction. Five articles mentioned that Virtual Laboratories may lead to reduced motivation and engagement as they do not provide possibilities for interpersonal communication. Four articles refer to the importance of the feeling of belonging to the community, which is not possible in Virtual Laboratories if the possibility of interpersonal communication is not provided. Four articles state the importance of interpersonal communication as a life soft skill that should not be omitted. Three articles refer to the

importance of scientific communication skills and interpersonal communication in this context. Two articles mention limited possibilities for the discussion and collaboration in Virtual Laboratories and two articles refer to the importance of a discussion as a part of inquiry skills. Other articles point that more attention should be driven to possibilities for interpersonal communication in Virtual Laboratories, highlighting the importance of communication as a part of learning strategy, its importance for building critical skills and knowledge. Two articles focus on the importance of developing personal relations between students and teachers for the educational process through interpersonal communication and one article mentions the importance of the interactions between teachers and students. Two articles highlight the importance of multimodal communication possibilities in Virtual Laboratories: combining verbal communication with image helps train thinking skills.

RQ6. What is a Virtual Laboratory in the articles that address different issues related to interpersonal communication?

As for a Virtual Laboratory, this tool is seen by half of the articles (seven) as an isolated virtual space for object manipulation. Six articles see a Virtual Laboratory in a more extended place, as inserted in another educational platform. And one article sees a Virtual Laboratory as an educational space itself, that integrates all-purpose tools in one virtual space. These results are presented in Table 3.

Table 3. Virtual laboratory in the articles related with interpersonal communication

Virtual Laboratory Concept	Total Articles
A space for simulated experimentation, manipulation on physically non-existent objects and evaluation of the results	**7**
A space for simulated experimentation and manipulation on physically nonexistent objects in a more extended educational environment (e.g., a platform)	**6**
VL is a platform that helps the students to generate visual representations of real-world experiments, as well as a screen design that shows animations, videos and simulations of the experiments, and graphical results. Each VL experiment offers interactive animations, simulations, and videos of experiment. The user can perform, measure, and study the experiments.	**1**

Source. Own elaboration.

4. Discussion

After answering the *RQs* that guided the study and analyzing the results in accordance with the main research questions, a total of five findings were identified, as presented below.

a) Interpersonal communication remains undercovered in the main focus.

This could be attributed to the demand driven by technical and natural disciplines, prompted by the urgent shift to virtual education, coupled with these disciplines' limited readiness for the challenge and the critical need for laboratory experiments. Given that most of the articles are centered on higher education, this emphasis may be due to the depth of study expected at this level compared to lower educational levels and the stronger alignment of university laboratories with career preparation. Additionally, higher education often involves specialized laboratories, leading to the development and testing of a wide array of tools across different disciplines. Notably, many articles focus on diverse pedagogical objectives, which may explain the limited emphasis on interpersonal communication in the main focus. Defining pedagogical perspectives is a foundational

step in educational planning, providing a robust framework for enhancing communication and ensuring that communication strategies align with learning objectives. Furthermore, the social dimension of learning heavily relies on the structure of technological environments, which is still evolving in technical education. As our results indicate, it is not adequately considered in social sciences and humanities. Therefore, in-depth study of interpersonal communication within the primary focus cannot occur until these environments are properly developed and tested.

The analysis of author keywords in Figure 3 also underscores the dominance of pedagogical aspects in virtual distance learning and remote education technology, with communication being a peripheral topic for most authors.

Generally, interpersonal communication does not hold the primary focus in these articles for several reasons. Firstly, the pandemic accelerated the development of Virtual Laboratories in areas where it was urgently required. Secondly, the diverse range of pedagogical contexts appears to necessitate a preliminary step before integrating interpersonal communication as a central focus. Lastly, the ongoing development and testing of technological environments need further attention before interpersonal communication can become the primary focus.

The main trend coincides with the one described by Raman *et al.,* (2022). Despite the decreased ability for personal communication discovered during pandemic school closure (Kaputa *et al.,* 2022), interpersonal communication issues still did not enter the researchers' attention. From this finding, we can conclude that interpersonal communication remains staying out of focus in the settings of a Virtual Laboratory and its importance as a fundamental competency for professional and daily life (UNICEF, 2017; Kirsch & Lennon, 2017; Battelle for Kids, n.d.; Carretero *et al.,* 2017; UNESCO, 2016) generally is not recognized. In this regard, it can be seen that despite the importance of interpersonal communication competency, and its decline during the pandemic, this topic is still underrepresented in Virtual Laboratory research.

b) Technical and natural disciplines in a formal educational context dominate in Virtual Laboratories.

Virtual Laboratories have not yet fully realized their potential for diverse educational contexts and disciplines (Yin & Shi, 2022; Dobrzański & Honysz, 2010). From our perspective, the next phase in Virtual Laboratories research involves their expansion into humanities and social sciences, where diverse collaborative activities are essential. While the need for laboratory work may not be as apparent in these fields, they still require interaction among peers and educators for discussions and concept development (Gubsky *et al.,* 2022). This also involves integrating data visualization tools, object manipulation (Senapati, 2022), and interpersonal interactions for tasks like database creation, analysis, and result discussions. For instance, digitized manuscript analysis can be conducted globally across research laboratories. It's possible that formal educational institutions and similar entities may not fully grasp the versatile applications of Virtual Laboratories across their academic domains. Therefore, a more precise examination of awareness and acceptance of Virtual Laboratories in various academic fields, emphasizing reasons for their adoption and potential development within educational institutions, is warranted. Such exploration can shed light on the benefits they offer to students.

Another aspect to consider in cooperative research settings is the development of language systems for international collaboration in Virtual Laboratories across various disciplines, educational levels, and contexts. It's evident that Virtual Laboratories are currently in the research phase of infrastructure development and testing concerning specific learning objectives. Research has been directed toward virtual platforms enabling global access (Lei *et al.,* 2022), allowing users of diverse languages to navigate and engage with content. However, this research has not yet delved into interpersonal communication among users. While Virtual Laboratories possess the potential to break free from the constraints of conventional formal education (Martín-Gutiérrez & González-Marrero, 2017), this transformation remains unrealized. As Virtual Laboratories extend to non-formal educational settings like museums (Moldovan & Bocoş-Binţinţan, 2015), issues pertaining to interpersonal communication will gain prominence. In such contexts, where collaborative groups may be physically separated for extended periods, effective communication becomes a more critical consideration.

We believe employing a Virtual Laboratory in an informal context (Eshach, 2007) is feasible, provided that user-friendly open software is available for adoption. Previous research indicates that technology adoption significantly impacts communication possibilities among extended family members (Tee *et al.,* 2009).

c) The research on interpersonal communication is insufficiently addressed in the main objectives and results and is often reported as an additional result.

Basically, these results point out the effectiveness of use of basic channels for interpersonal communication, such as chats, messengers, and external tools such as Microsoft Teams. In some studies, it is reported that the students felt in need for interpersonal communication and in other cases the results are opposite. This last point could be explained by the reason that in the later studies the students had excess to both types of the laboratory, physical and virtual, so in this case they didn't have a chance to feel social isolation at full level. On the other hand, as demonstrated in the previous findings, research continues to focus on developing and testing Virtual Laboratories for various pedagogical purposes. Therefore, as a vital prerequisite for integrating interpersonal interaction into primary objectives, it is essential to first develop and test a suitable virtual environment aligned with well-defined pedagogical goals. This approach acknowledges that the issues surrounding personal interactions will be highly contextualized in each case. As technology advances and students' and academics' ability to create and manage these educational settings improves, a diverse range of context-specific interpersonal interaction issues is expected to emerge and be addressed in the future. One explanation for why interactional issues are primarily addressed in research related to technical and natural disciplines could be attributed to the expertise of academics in these fields. Educational professionals in these domains are better equipped from their areas of specialization to create digital educational environments. Conversely, interpersonal communication issues may not be a primary focus of this research, as they align more closely with professionals in social sciences and humanities. This distinction may also clarify why personal interactions are extensively covered in additional results, as these observations serve as complementary outcomes that cannot be ignored, given that personal interaction is a constant presence in any educational process. However, some additional results stem from fragmented educational virtual environments.

Additional results report the importance of interpersonal communication for learning outcomes in general, highlighting especially cognitive, affective, and metacognitive learning dimensions (Sawyer, 2005). As technical and natural sciences prevail in selected articles, these disciplines usually consider experimenting and manipulating digital objects and this is seen as the only goal for the development of these spaces, communication is simply seen as not needed from this perspective. At the same time, there is positive evidence that the research on Virtual Laboratories, even for the purposes of technical and natural sciences objectives, is starting to appeal to the problem of interpersonal communication in the context of a Virtual Laboratory. As evident in Figure 4, five articles in the analyzed corpus discuss reduced motivation and engagement associated with Virtual Laboratory work, while four articles highlight the potential for isolation and psychological detachment experienced by learners in these environments. This shift likely reflects the transformation of Virtual Laboratories from spaces focused on object manipulation to more comprehensive learning environments. Table 3 reveals that this perspective on Virtual Laboratories represents a relatively recent trend.

The focus on external basic communication possibilities, simple forms as chats and isolated spaces for experimenting indicates a lack of language systems developed for the settings of a Virtual Laboratory.

d) The importance of interpersonal communication is seen from a variety of pedagogical reasons, but mainly for the reason of its importance for collaborative learning.

This result in general corresponds to the necessity for considering discussion and small group work for construction of a learning experience (Akpan *et al.,* 2020) and refers to interpersonal communication in its social dimension of learning. A reference to interpersonal communication skills as soft skills for life is found, which corresponds to the importance of developing this skill in global frameworks (UNICEF, 2017; Kirsch & Lennon, 2017; Battelle for Kids, n.d.; Carretero *et al.,* 2017).

Regarding these frequently covered topics and considering that the majority of analyzed articles are related to technical and natural sciences, there appears to be a gap in addressing several specialized topics that significantly impact the effectiveness of interpersonal communication. Some of these less-explored subjects include language and terminology standardization, crucial for ensuring clarity and precision in communication within Virtual Laboratories. As mentioned in previous findings, another unaddressed area is cross-cultural communication, with a focus on the challenges and opportunities it presents for promoting

cultural sensitivity and effective cross-cultural collaboration. Additionally, a pedagogically oriented topic is the assessment of effective communication to evaluate the quality of interpersonal interactions within Virtual Laboratory settings. These assessment tools are essential for enhancing the design and technological features of these environments to better cater to the needs of interpersonal interaction.

Next dimension to be widely presented in the mapping of the topic of interpersonal communication is the affective dimension: five articles state that a lack of communication leads to reduced motivation and engagement, four articles say that the lack of communicative possibilities leads to isolation and does not support the feeling of belonging to the community, two articles point out the importance of communication between teachers and students for establishing effective and trustful relationships.

Regarding the affective dimension, research could delve deeper into topics such as feedback mechanisms to enhance student engagement and boost confidence. Another overlooked area in the context of Virtual Laboratories is inclusivity. Ensuring accessibility for all learners, including those with disabilities, is vital to foster inclusiveness and engagement for everyone.

One article covers the cognitive dimension of learning, which is the importance of interpersonal communication for developing critical thinking skills, and one article highlights its importance in the metacognitive dimension and points out a learning-to-learning strategy. Two articles consider it important to see interpersonal communication as a part of extended communication that occurs in the settings of a Virtual Laboratory in a context of a variety of image patterns and diagrammatic representations. And one article merely highlights the importance of giving more attention to the issues of interpersonal communication.

From these results, it becomes evident that the topic of multimodal communication is underrepresented in research related to Virtual Laboratories and interpersonal communication. This issue holds significance across various disciplines and educational levels. Multimodal communication, encompassing text, audio, and visual elements, has the potential to enhance the effectiveness of personal interactions and act as a catalyst for communication. The neglect of this topic may also be linked to the limited exploration of virtual spaces in the context of interpersonal communication, hindering a comprehensive understanding of social and cultural settings (Schreiber & Valle, 2013).

The finding reveals that while interpersonal communication issues may be underrepresented in terms of focus, primary objectives, and results, researchers are gradually acknowledging the significance of the social dimension of learning and its intersection with other dimensions within the context of Virtual Laboratories. Nonetheless, several specialized topics related to personal interaction continue to be insufficiently explored.

e) The concept of Virtual Laboratory adopted by researchers may guide the way the importance of interpersonal communication is seen.

From a social learning standpoint, viewing a Virtual Laboratory as a platform holds greater promise for the future. Such an approach establishes a centralized hub where students, instructors, and resources converge. These hubs have the potential to foster a sense of community, whether it's in a formal, informal, or non-formal context, by offering a shared space for collaboration, streamlining user connections and interactions.

Based on a small quantity of these examples, we cannot derive conclusions if there is a direct relationship between studying interpersonal communication issues and Virtual Laboratory settings, but it can be said that with the expanded vision on what a Virtual Laboratory can be, new trends in researching interpersonal communication in its settings will arise. Seen as a broader virtual space, a platform itself, a Virtual Laboratory can integrate the possibilities for various forms of interpersonal communications, verbal and visual, discussions on data construction and visualization, manipulating different kinds of digital objects as a part of collaborative teamwork across the globe.

5. Conclusions

In this research, our primary goal was to contribute to the field of digital transformations in education by focusing on a Virtual Laboratory as an emerging virtual space for collaboration to enhance interpersonal communication by identifying problematic situations associated with this subject. The study arrived to the following findings: a) Interpersonal communication remains undercovered in main focus; b) Technical and natural disciplines in a formal educational context dominate in Virtual Laboratories; c) The research on

interpersonal communication is insufficiently addressed in main objectives and results and often is reported as an additional result; d) The importance of interpersonal communication is seen from a variety of pedagogical reasons, but mainly for the reason of its importance for collaborative learning; e) The concept of Virtual Laboratory adopted by researchers may guide the way the importance of interpersonal communication is seen.

For future research, our findings underscore the need for scholars to expand their horizons and delve deeper into the nuances of interpersonal communication within Virtual Laboratories. Interdisciplinary collaboration is encouraged, as experts from diverse fields should come together to explore this subject comprehensively. Precise descriptions of Virtual Laboratory settings are recommended, especially when examining interpersonal communication development. Additionally, there's a call to redefine the concept of Virtual Laboratories, emphasizing collaborative work in national and global interdisciplinary teams. Language systems supporting interpersonal communication in various languages should also be a priority.

Practitioners can consider utilizing Virtual Laboratories to enhance lifelong competencies across different disciplines and contexts. This tool has potential in non-formal education, enabling digital artifact study, modeling, discussion, data gathering, and global collaborations. Curriculum designers should integrate communication-related learning objectives into Virtual Laboratory courses, promoting effective interpersonal communication among students. Furthermore, the study highlights the need to shift from a primarily self-directed learning approach to a more collaborative work within Virtual Laboratories. Exploring Virtual Laboratories as platforms can activate multidimensional learning and drive innovations in formal and non-formal education, enhancing global communicative and collaborative competencies.

Certain limitations of the study should be acknowledged. To gain a more comprehensive understanding of how interpersonal communication issues are represented in Virtual Laboratory settings, future research should consider expanding the scope to include various documents like technical reports and conference proceedings, extending beyond traditional scientific databases. Embracing a broader range of sources in literature reviews can stimulate innovation and creativity, exposing researchers and practitioners to emerging trends and diverse perspectives that may inspire novel approaches to the subject.

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Conceptualization: I.A., M.A.C.A; Methodology: I.A.; Research: I.A.; Supervision: I.A.; Writting (original draft): I.A.; Writing (review & edition): R.L.U.C.; M.A.C.A.; Visualization: R.L.U.C.

Conflicts of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix

Table 1. Interpersonal communication in the articles related to Virtual Laboratories

N	Article title	Author/s	Year	Country, Language	Journal Category Quartile (WoS/Scopus)
1	Ecosystem for the deployment and management of virtual laboratories based on the standard IMS LTI	Santamaria-Buitrago, F. .; Ballesteros-Ricaurte, J. A.; Gonzalez-Amarillo, Á. M.	2019	Colombia, English	Revista Facultad de Ingeniería. Q3 (WoS)
2	ReImagine Lab: Bridging the Gap Between Hands-On, Virtual and Remote Control Engineering Laboratories Using Digital Twins and Extended Reality	Alsaleh, S.; Tepljakov, A.; Kose, A. Belikov, J.; Petlenkov, .	2022	Estonia,English	IEEE Access. Q2 (WoS)
3	Impact of remote experimentation, interactivity and platform effectiveness on laboratory learning outcomes	Achuthan, K; Raghavan, D.; Shankar, B.; Francis, S.P.; Kolil, V.K.	2021	India, English	International Journal of Educational Technology in Higher Education. Q1 (WoS)
4	Analysis of Cooperative Skills Development through Relational Coordination in a Gamified Online Learning Environment	Estriegana, R.; Medina-Merodio, J.-A.; Robina-Ramirez, R.; Barchino, R.	2021	Spain, English	Electronics, by MDPI. Q3 (Scopus)
5	Development of hybrid practice sessions in the chemistry lab reinforced by teamwork activities and video-enhanced learning	Calatayud, M.; Cifuentes-Cabezas, M.; Rodriguez-Lopez, A.D.; Hernandez-Perez, L.; Carrillo-Abad, J.	2022	Spain, Spanish	Revista de Docencia Universitaria. Q4 (WoS)
6	Interaction Identified as both a Challenge and a Benefit in a Rapid Switch to Online Teaching during the COVID-19 Pandemic	Parkes, R.S.V; Barrs, V.R.D.	2021	China, English	Journal of Veterinary Medical Education. Q3 (WoS)
7	Thinglink and the Laboratory: Interactive Simulations of Analytical Instrumentation for HE Science Curricula	Jeffery, A.J.; Rogers, S.L.; Pringle, J. K.; Zholobenko, V.L.; Jeffery, K.L.; Wisniewski, K.D.; Haxton, K.J.; Emley, D.W.	2022	England, English	Journal of Chemical Education. Q2 (WoS)
8	Comparison of In-Person and Virtual Labs/Tutorials for Engineering Students Using Blended Learning Principles	Schnieder, M.; Williams, S.; Ghosh, S.	2022	England, English	Education Sciences, by MDPI. Q3 (Scopus)
9	The 5I's of Virtual Technologies in Laboratory Teaching for Faculties of Higher Education in Kerala	Bose, L.S.; Humphreys, S.	2022	India-Denmark, English	Journal of Science Education and Technology. Q1 (WoS)
10	A task model for supporting virtual laboratory based on inquiry skills, social and scientific communication	Fatmaryanti, S.D.; Pratiwi, U.; Akhdinirwanto, R.W.; Sulisworo, D.	2022	Indonesia, English	International Journal of Evaluation and Research in Education. Q3 (Scopus)
11	Predictors of the Use of ICTS in Higher Education: Relevance and Readiness of Universities for Their Implementation	Tokareva, E.; Malysheva, O.; Smirnova Y.; Orchakova L.	2021	Russian Federation, English	International Journal of Emerging Technologies in Learning. Q4 (Scopus)
12	Creation of a virtual technology laboratory and organization of training for highly qualified personnel [Создание виртуальной технологической лаборатории и организация обучения при подготовке кадров высшей квалификации]	Nemtinov, V.A.; Manaenkov, I.M.; Nemtinova, Y.V.	2020	Russian Federation, Russian	Vysshee Obrazovanie v Rossii. Q3 (Scopus)

Continued from Table 1

13	Guided inquiry model through virtual laboratory to enhance students' science process skills on heat concept [Model inkuiri terbimbing melalui laboratorium virtual untuk meningkatkan keteram-pilan proses sains siswa pada konsep kalor]	Gunawan, H.A.; Hermansyah, H.L.	2019	Indonesia, English	Cakrawala Pendidikan. Q3 (Scopus)
14	Electronic study guides for applied ba-chelor's degree programs	Maltsev, D.V.; Genson; E.M. Repetskiy, D.S.	2019	Russian Federation, Russian	Vysshee Obrazovanie v Rossii Q3 (Scopus)

Source. Own elaboration with the information obtained from the SCOPUS and Web of Science databases.

Appendix

Table 2. Objectives and results of the analyzed articles

No.	Main objectives	Main results achieved	A[a]	B[b]	What are the results related to interpersonal communication, if not reported directly as main results achieved?
1	To develop an ecosystem that fosters academic processes characterized by openness, reusability, and interoperability	To create a Virtual Laboratory ecosystem that encompasses diverse resources and simulators, with the purpose of streamlining decision-making in areas such as learning management, research, and related processes	No	Yes	Interpersonal communication is considered in the development: mentions simple forms to enhance interpersonal communication as a chat, and other social tools for interactions between teachers and students
2	To propose a framework for utilizing digital twins and extended reality to enhance student engagement by promoting collaboration across various modes of laboratory experiences, including remote, virtual, and take-home setups.	The proposed framework improved the usability of the simulated laboratory environment.	No	Yes	Interpersonal communication is considered in the framework: in virtual and remote laboratories, there are little opportunities for students to develop social skills and collaborate. It is viable to create a shared virtual reality experience using extended reality, where students can be presented as avatars and may communicate as a group
3	To assess and compare the PL-UTM (Physical Universal Testing Machine) and RT-UTM (Remote Universal Testing Machine) features with respect to the transacttional distance; to test RT virtual laboratory platform for effectiveness and for achieving knowledge results	Design of a remote lab; capture of the structure and interactivity of PL-UTM and RT-UTM through the Transactional Distance Theory; conceptual understanding in remote *vs* physical and integrated remote and physical laboratory environments	No	Yes	Enhanced interaction, or interpersonal communication between students and teachers is aided by the integration of LMS (Learning Management System) within the Virtual Laboratory framework; students who were learning remotely had more questions on the theory, procedural processes and experimentation
4	To introduce an online learning environment that encompasses various web-based resources and online learning environment on relationships and the development of communicative and cooperative competencies	The proposed learning environment positively influences communication and relationships, fostering the development of cooperative competence; this approach leads to enhanced competency in these areas	Yes	No	-
5	To evaluate the proposal of instructtional design	The employed strategy had a very high acceptance and allowed students to train in the management of applied experimenttation procedures	No	Yes	Using Microsoft Teams for supporting interpersonal communication is seen by the majority of students as the safest way to work with the data collected in the laboratory under pandemic restrictions
6	To assess students' perceptions of the rapid implementation and transition of the traditional curriculum to one based entirely online during pandemic; to suggest improvements to veterinary education	Online learning can be as effective as face-to-face in achieving their learning outcomes; time-saving aspect of online teaching and interactive elements such as recorded lectures, online quizzes, and chat boxes were appreciated by students; shyer students felt more confident using chat boxes to ask questions, highlighting the need to address communication skills and foster a comfort-table environment for asking questions in physical classrooms	Yes	No	-

Continued from Table 2

7	To assess the efficacy of virtual simulations of analytical instruments in applied science education, demonstrating how educators can create customized virtual laboratory resources without extensive expertise or training	The style of online virtual learning resource presented is viewed as beneficial by learners and teachers, if planned as a supplement to physical learning; a Thinglink platform is a powerful but imperfect tool for the creation of virtual learning resources relating to laboratories	No	Yes	One participant emphasized the social advantages of synchronous lectures that incorporate discussion-based elements; traditional approaches alone are generally seen as insufficient
8	To create a virtual version of the in-person lab to be as interactive as possible without developing new software; to compare students' reflection on learning outcomes and confidence in a Virtual Laboratory and in-person lab	Greater confidence reported by students in Virtual Laboratory in theoretical understanding; interactivity and possibility to complete the virtual lab anytime is appreciated; both the virtual and the in-person lab should be offered	No	Yes	Out of all the students, only two specifically mentioned that they missed the face-to-face interaction and the opportunity for interpersonal communication in the physical laboratory setting
9	To assess and quantify the effecttiveness of training faculty members in laboratory teaching by utilizing Information and Communications Technology (ICT) methods	The experimental group demonstrated superior performance in terms of understanding concepts, conducting experiments, and achieving accurate results compared to the control group. There was a positive transfer of training from virtual lab exercises to real lab settings, as evidenced by higher average scores in the experimental group. Teachers generally supported the use of virtual laboratories as an effective teaching tool, while students considered them as a valuable supplement to traditional labs rather than a complete replacement	No	No	-
10	To obtain an initial investigation and design of a task model using a Virtual Laboratory with the purpose of fostering the development of social and communication skills within an inquiry-based context	Designing a task model is crucial for cultivating inquiry skills, as well as promoting social and scientific communication among future physics teachers	Yes	-	-
11	To identify the factors that influence the readiness of higher educational institutions to adopt and integrate information and communication technologies (ICTs)	Many students and teachers lack awareness of MOOCs and the potential of distance learning and remote laboratories; junior students may have limited knowledge about MOOCs and virtual laboratories; students and teachers generally prefer offline classes and face-to-face communication over the use of ICTs; research is needed to develop new approaches that enhance interaction	Yes	-	-
12	To test the Virtual Laboratory prototype created in a virtual learning environment	The established virtual learning environment and a communicative environment has a positive impact on enhancing the quality of students' knowledge	Yes	-	-
13	To investigate the impact of implementing the guided inquiry model using a Virtual Laboratory on students' science process skill	The implementation of guided inquiry models through virtual laboratories has a significant positive impact on students' science process skills, particularly in the areas of hypothesizing, practicing, and communicating	Yes	-	-
14	To suggest guidelines for the creation and integration of electronic materials	Recommendations for organizing electronic resources; guidelines for remote interaction between the teacher and students	Yes	-	-

[a] A = Interpersonal communication addressed in main results.
[b] B = Interpersonal communication addressed in additional results of the article.

Source. Own elaboration.