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Design of immersive virtual reality training for endoscopic surgery

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Abstract: *Endoscopic surgery training is faced with limitations due to a shortage of specialized instructors and limited access to technological equipment. Virtual reality training offers a possible solution by providing accessible and efficient practice opportunities. This exploratory study aimed to understand the current applications of virtual reality in medicine and the specific challenges that surgeons face in Brazil regarding endoscopy training. To achieve this, a non-systematic literature review (NSLR) was conducted to understand the current applications of virtual reality in medicine and the specific challenges faced by surgeons in Brazil regarding endoscopy training. This was followed by a systematic literature review (SLR) to obtain a deeper understanding of the characteristics of virtual reality systems used for endoscopic surgery training. Additionally, the study designed and tested a proof of concept through an immersive virtual reality system with endoscopic surgery specialists, using the Design Science Research methodology. The results indicate that immersive virtual reality training shows potential as an effective means of enhancing surgical skills. Future studies can further explore and evaluate the effectiveness of immersive virtual reality training in endoscopic surgery with larger sample sizes and the inclusion of multiple institutions and specialties to ensure generalizability.*
Keywords: *Virtual reality. Education. Endoscopic surgery.*

1 Introduction

Endoscopic surgery has revolutionized the field of medicine by allowing surgical interventions to be performed without the need for large incisions, resulting in reduced bleeding, infections, and faster recovery. However, with the emergence of this technique, the challenge of training surgeons to perform it efficiently and safely has also arisen (CAVALINI ET AL., 2014). Learning domains have been debated for many years, including cognitive, affective, and psychomotor development. In the case of endoscopic surgery, the area that requires the most training and development is the psychomotor domain. However, practice is necessary, and the availability of equipment, instruments, and personnel to help and supervise correct training is restricted due to a lack of trained professionals and the high cost of equipment.

This exploratory study began with a non-systematic literature review (NSLR) to understand the current applications of virtual reality in medicine and the specific challenges that surgeons face in Brazil regarding endoscopy training. We then conducted a systematic literature review (SLR) to obtain a deeper understanding of the characteristics of virtual reality systems used for endoscopic surgery training. Using the identified characteristics, we applied the design science method to ideate, prototype, and test the potential impact of virtual reality on endoscopic surgery training.

2 literature review

In this section, the data collected in the non-systematic literature review (NSLR) and the systematic literature review (SLR) are presented. As mentioned in the previous section, the NSLR provided an initial understanding of the applications and impact of virtual reality in the field of medicine and the challenges that surgeons face in Brazil regarding endoscopy training.

2.1 non-systematic literature review

Corroborating the long-standing debate on knowledge retention across different learning modalities, Dale (1969, cited in Leite, 2018) highlighted that when individuals engage in practical activities and are allowed to do so, there is a 90% retention of knowledge, as shown in Figure 1. This approach aligns with Leite's (2018) active methodology, which places students as the main agents of their learning. Therefore, it is evident that virtual reality training can efficiently enhance the psychomotor domain of specialists being trained in endoscopic surgery through practical and immersive experiences.

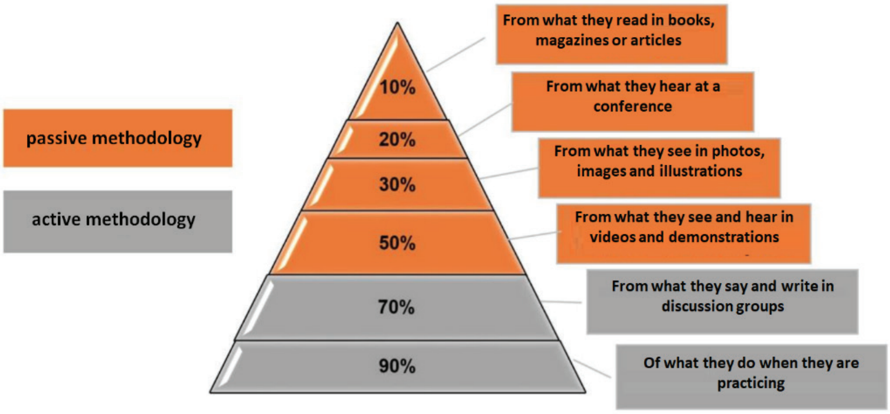

FIGURE 1. Learning pyramid (Source: Adapted from (Dale, 1969 cited in Leite, 2018))

After conducting the non-systematic literature review (NSLR) on medical training efficiency, we found compelling arguments that support the use of virtual reality in the medical field. Specifically:

Virtual reality has been shown to increase knowledge retention by 80% (Sankaranarayanan et al., 2018).

Students who receive virtual reality training are 275% more confident in applying what they learned compared to those who receive traditional training methods (Chai et al., 2017).

Virtual reality training is, on average, four times faster than traditional classroom training (Chai et al., 2017).

Firefighting training conducted in an operating room using virtual reality results in students who perform 250% better than those trained using traditional reading and lecture methods (Sankaranarayanan et al., 2018).

Students who receive virtual reality training are 400% more focused than those using traditional training methods (Chai et al., 2017).

Virtual reality training leads to fewer performance errors and higher accuracy compared to conventional training methods (Sankaranarayanan et al., 2018).

Students using virtual reality are approximately four times more emotionally connected to the content than those in traditional classrooms (Chai et al., 2017).

Virtual reality simulation significantly improves learning performance compared to screen-based simulation training (Gutiérrez et al., 2007).

One other noteworthy study involves the use of virtual reality simulation for assessing the communication skills of healthcare professionals in a manner similar to high-fidelity mannequin-based simulation. The specialists involved in this training focus on the treatment of patients suffering from cardiopulmonary arrest or cardiovascular emergencies, also known as ACLS.

As highlighted by Katz et al. (2020), the cost of virtual reality simulation for ACLS training was found to be 83% less than the cost of mannequin-based simulation. Additionally, the same authors found that VR-based ACLS training required half the time for students to complete and only 25% of the staff needed to run the VR simulations compared to traditional ACLS simulation.

Education and training in laparoscopic surgeries are facing a significant deficit and slow evolution in Brazil. According to Nácul, Cavazzola, and Melo (2015), there are various factors contributing to this, such as the lack of information and misinformation about the method, the economic downturn affecting doctors' investments in updating their skills, high equipment costs, deficiency in medical residency courses and programs, and the conservatism of surgeons in maintaining old surgical dogmas. Additionally, the lack of organizational and structural know-how, the specific technical aspects of learning, and the disconnection between surgical specialties pose complex educational difficulties.

In this context, the use of virtual reality in medical training has emerged as a practical and effective solution. Specifically, in laparoscopic surgery training, virtual reality can offer a safe and low-cost alternative to traditional methods. For example, virtual reality simulations can provide an immersive learning experience that is not limited by physical space or resources. It can also offer a way to overcome some of the aforementioned challenges, such as the lack of development of surgical schools oriented towards laparoscopy.

In order to better understand the characteristics of these training systems, a SLR was conducted and is presented in the following section.

2.2 Systematic Literature Review

In this section, a systematic literature review is conducted, which is divided into four steps, as shown in Figure 2.

- Define the review protocol: In this step, the criteria for selecting studies are established, including the research question, the types of studies to be included, the search strategy, and the inclusion and exclusion criteria.
- Data collection: In this step, relevant studies are identified through a comprehensive search of electronic databases and other sources, such as reference lists of relevant articles.
- Data filtering: In this step, the collected data are screened to determine which studies meet the inclusion criteria established in the review protocol.
- Data synthesis: In this final step, the data from the selected studies are synthesized to address the research question.

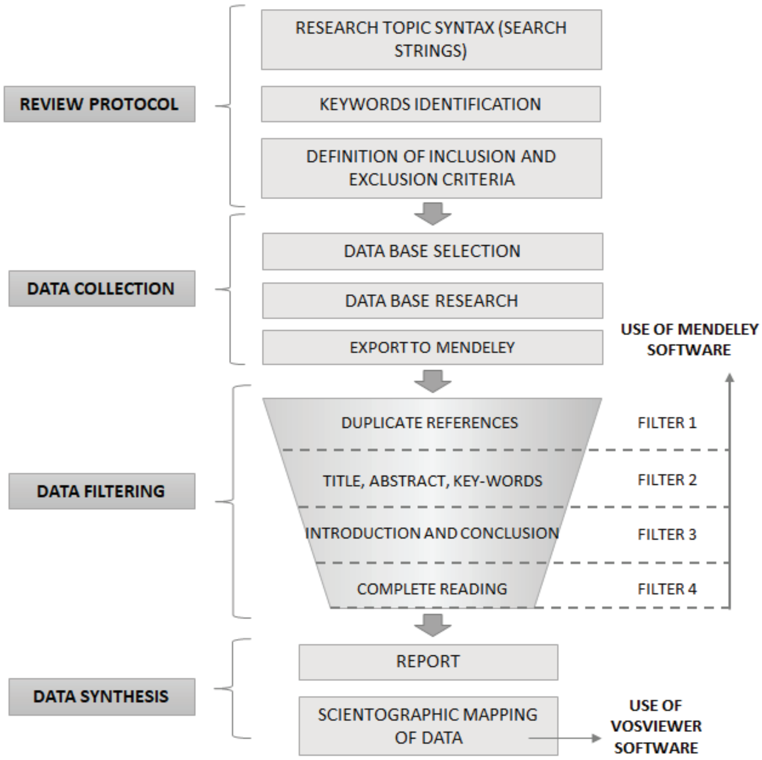

FIGURE 2. Systematic literature review (source: from the author)

In the review protocol phase, as illustrated in Figure 3, the process begins with an analysis of the research topic syntax. This is necessary to generate various search strings with the same topic across different databases.

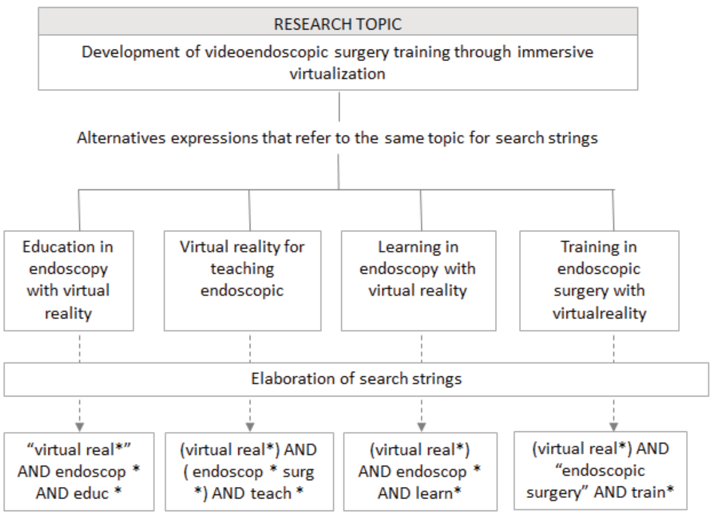

FIGURE 3. Search strings (source: author).

To collect comprehensive and high-quality articles, Scopus, Web of Science, and Pubmed databases were selected as sources. Various search strings were used in each database resulting in a total of 266 articles, with Scopus yielding 138 articles, Web of Science with 95 articles, and Pubmed with 55 articles, as shown in Table 1. The search string "virtual real * AND endoscop * AND educ *" had the highest number of articles, with a total of 126 articles found.

Table 1. Data collection.

Strings	Scopus	Web of Science	pubmed	Total
String 1 "virtual real*" AND endoscop * AND educ *	58	37	31	126
String 2 (virtual real*) AND (endoscop * surg *) AND teach*	13	15	11	39
String 3 (virtual real*) AND endoscop * AND learn*	34	21	1	56
String 4 (virtual real*) AND "endoscopic surgery" AND train*	21	12	12	45
Total	126	85	55	266

SOURCE: from the author.

In relation to data filtering, Table 2 presents the initial inclusion and exclusion criteria for this study.

Table 2. Inclusion and exclusion criteria.

Criteria	Inclusion	Exclusion
Scope	Research addressing the topic of the application of virtual reality in endoscopy teaching	Research addressing the topic of virtual reality without a teaching approach through endoscopy
Reference type	Articles published in peer-reviewed journals and conference proceedings	
Access	Works accessible through CAPES Journals Portal at UFPR, Google Scholars, and free publisher portals	Works whose viewing requires paid registration.
Timeframe	Papers published in the last 5 years	

SOURCE: from the author.

Figure 4 depicts the filtering process, which involved four steps. Firstly, the Mendeley software was used to exclude duplicate references, resulting in 107 articles. Secondly, the titles, abstracts, and keywords of these articles were read, which led to the retention of 58 articles. Thirdly, the introduction and conclusion sections of the articles were read, resulting in 32 articles remaining. Finally, the full articles were read, and only 21 articles met the inclusion criteria and were selected for further analysis.

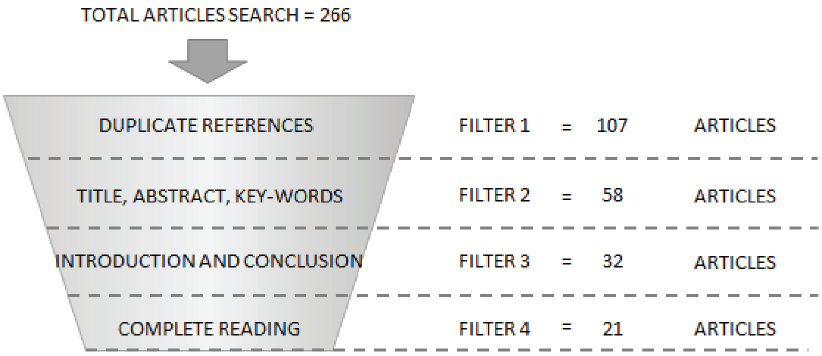

FIGURE 4. Article filtering (source: author).

Table 3 presents the references that remained after the rigorous filtering process. During the thorough reading of the articles, a crucial point of consideration was the analysis of the characteristics of virtual reality or virtual computer simulations in enhancing the educational process of endoscopic surgery.

Table 3. References obtained from filter 4.

NUMBER	REFERENCES
1	ALVAREZ et al. (2020)
2	CHHEANG et al. (2020)
3	ELESSAWY et al. (2021)
4	Friedrich et al. (2018)
5	GASPERIN, ZANIRATI and CAVAZZOLA (2018)
6	GUEDES et al. (2019)
7	HAGELSTEEN et al. (2019)
8	HASAN and IQBAL (2017)
9	HOOPES et al. (2020)
10	KHAN et al. (2017)
11	KHOO et al. (2021)
12	KORZENIOWSKI et al. (2017)
13	KOSIERADZKI et al. (2020)
14	LESCH et al. (2020)
15	OSTERBERG et al. (2019)
16	PORTO et al. (2020)

NUMBER	REFERENCES
17	SATTAR et al. (2019)
18	SIRIMANNA & GLADMAN (2017)
19	VAPENSTAD et al. (2017)
20	YIASEMIDOU et al. (2017)
21	ZAHIRI et al. (2018)

SOURCE: author.

The scientographic data mapping, which was based on the articles that passed through the filtering process of the systematic literature review, provides valuable insights into the current research landscape in the area of endoscopic surgery training, specifically laparoscopic surgery. The Vosviewer program was used to create the data mapping, which illustrates the relationship between research topics worldwide. The use of Vosviewer is important because it allows for the visualization of the co-occurrence of keywords in a scientographic mapping, providing a comprehensive view of the research landscape. Figure 5 presents a particularly interesting representation of this mapping, highlighting "virtual reality" as the most related keyword. This finding underscores the innovative nature of the research presented in this study on a global scale.

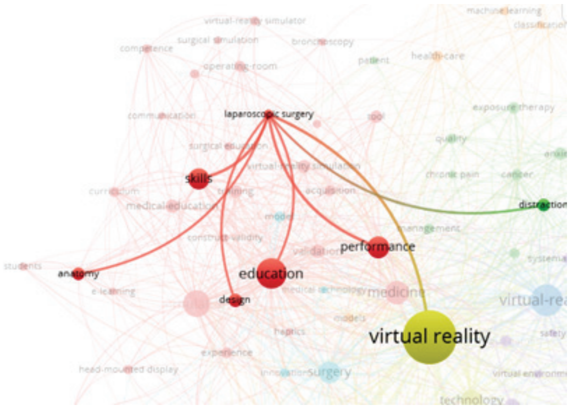

FIGURE 5. Data mapping of the training relationship in laparoscopic surgery (source: author).

The data mapping presented in Figure 5 highlights the main words associated with the research, including "virtual reality", "laparoscopic surgery", "performance", "knowledge", and "education". This indicates that the topic and research presented in this study are relevant to various areas discussed thus far. In the data synthesis phase of the systematic literature review, it is noteworthy that while many investigations involve training in endoscopic surgery using various equipment and simulators, immersion in the training is still important, as demonstrated in Table 5. As discussed in this research proposal, training with virtual reality can lead to higher knowledge retention compared to other methods.

Table 5. Synthesis of the characteristics of simulation equipment obtained from RBS

REF.	SIMULATION EQUIPMENT FOR ENDOSCOPIC SURGERY TRAINING																								VALUED SURGICAL PROCEDURE				
	SIMULATOR TYPE			NAME													CHARACTERISTICS												
	IMERSIVE VR	NON-IMMERSIVE VR	BOX TRAINER	BT N/M	HTC LIVE	LAPSIM	LAPMENTOR	NOTICE	PORTCAS	ROBOTIX	SIMBALL BOX	SIMISGEST-VR	SMART SIM	TAKE HOME BT	SIMULATION TIPS	MULTIPLE N/M	UBIQUITOUS LEARNING	HAPTIC FEEDBACK	INSTRUMENTS	AUDIO INSTRUCTIONS	VISUAL INSTRUCTIONS	VR GLASSES	SOFTWARE	TASK PERFORMANCE	APPENDECTOMY	CHOLECYSTECTOMY	SALPINGECTOMY	THIRTY. ESSENTIAL	VARIOUS PROCEDURE
1		X										X					X		X		X		X					X	
2	X				X												X	X	X		X	X	X						X
3		X				X												X	X		X		X	X			X		
4		X					X											X	X		X		X	X		X			
5		X					X											X	X		X		X	X		X			
6		X	X	X		X	X									X	X	X	X		X		X	X					X
7		X				X												X	X		X		X	X					X
8		X											X						X		X		X	X					X
9		X	X	X		X	X									X	X	X	X		X		X	X					X
10		X											X						X		X		X	X					X
11		X					X											X	X		X		X	X		X			
12		X						X										X	X		X		X	X		X			
13	X									X								X	X		X	X	X	X					X
14		X													X			X	X		X		X	X					X
15			X								X								X		X			X				X	
16		X				X												X	X		X		X	X					X
17	X															X	X				X	X							X
18		X					X											X	X		X		X	X	X				
19		X				X												X	X		X		X	X		X			
20		X	X											X		X	X	X	X		X		X	X		X			
21		X							X								X		X		X		X	X					X
TOTAL	3	17	4	2	1	6	6	1	1	1	1	1	2	1	1	4	7	15	20	0	21	3	19	18	1	6	1	2	11

SOURCE: the author.

To provide a comprehensive overview of the characteristics offered by different types of simulators, the following aspects are worth highlighting:

Ubiquitous learning: The device's ability to facilitate learning and training anytime and anywhere is known as ubiquitous learning (Álvarez, 2020), is essential in enhancing the accessibility of training for surgeons. This is particularly important for their psychomotor development in endoscopic surgery, as it allows them to practice and refine their skills in a more flexible manner, potentially integrating training into their daily routines, ultimately leading to more efficient and effective training.

Haptic feedback: The tactile sensation or force feedback that a user experiences when interacting with virtual objects in a virtual reality environment. In the context of endoscopic surgery training, haptic feedback is critical in providing the surgeon with a realistic sense of touch and force when they perform actions such as touching virtual organs, skin, needles, and other objects. This realistic sensation is achieved through the use of special haptic devices that can transmit a contrary force to the control when the user touches something in the virtual environment. This characteristic is essential in creating a more immersive and realistic virtual reality environment, which, in turn, enhances the effectiveness of endoscopic surgery training by allowing the surgeon to experience a more realistic surgical scenario.

Instruments: The controller with which the surgeon interacts with the simulation is known as the instruments. Its advantage lies in its similarity to real instruments in terms of operation. However, the haptic feedback feature is not inherent in it, so many simulators may have the instruments but lack haptic feedback. According to Hasan (2017), the surgeon's manual visual coordination, sense of depth, and ability to work in confined spaces are developed through the use of instruments.

Audio instructions: The voice audio guide provided within the simulation is known as audio instructions. It generates greater similarity with a real instructor within the simulation (Hasan, 2017).

Visual instructions: The visual effects that can guide the surgeon on how to perform the procedure are known as visual instructions (Khan, 2017).

VR glasses: The hardware that covers the visual field of the eyes in a 360-degree simulation, allowing the user to enter immersive virtual reality is known as VR glasses. According to Kozieradzki (2020), VR glasses provide students with a holographic experience that generates efficient learning in medicine, eliminating the need for a teacher to be physically present in the classroom.

Software: The program that generates virtual reality, whether immersive or not, is known as software. According to Hoopes (2020), simulators with software, such as box trainers, have significant advantages over those that do not, as they can recreate multiple surgical scenarios and offer interactive instructions on how to perform the procedure, thus shortening the learning curve. In the following section of this study, box trainer equipment will be presented.

Task performance: Performance indicators of the surgeon during the simulation, such as the duration of the procedure and the number of errors, among others that can be considered relevant within each procedure, are known as task performance. This type of resource is usually associated with software, but even so, some simulators may not have it, or it may be poorly developed (Chheang, 2020).

2.2 Training Systems In Endoscopic Surgery In Brazil

Endoscopic surgery simulators are available in some educational institutions, including renowned universities with medical courses in Brazil. However, these commercial-grade simulators can cost hundreds of thousands of Brazilian reals, making them unaffordable for many institutions. Furthermore, the number of simulators available is often limited, with just one available for an entire medical course, thus limiting their use by students.

According to a report by UFPR (2021), the Hospital das Clínicas - CHC-UFPR, acquired non-immersive endoscopy training equipment in April of this year (Figure 6), which required an investment of approximately R$ 1,200,000.00. (Brazilian reals) This significant investment has enabled the hospital to provide more opportunities for training and development for its medical residents.

As reported by a general surgeon at CHC-UFPR, "It is a significant improvement because the resident can practice a lot before touching the patient. The visual and tactile perception is practically the same as actual surgery. You can feel that we are touching the structures, making a cut or a suture. It's like a real situation."

FIGURE 6. CHC-UFPR team with the new equipment. (Source: UFPR, 2021)

Other equipment similar to the one shown in Figure 6 is used worldwide. A recent study by Elessawy et al. (2021) presents the evolution of equipment for endoscopic surgery simulators in virtual reality. However, this virtual reality technology is not fully immersive since it does not include VR glasses that enable the user to sense the 360-degree context. Instead, the user's view is limited to the monitor. The simulator used in this study is shown in Figure 7 and can also cost up to €100,000.00 (in Europe). If imported to Brazil, it would be similar in cost to the equipment purchased by CHC-UFPR.

FIGURE 7. Non-immersive virtual reality equipment. (Source: Elessawy et al., 2021)

It's worth noting that endoscopic surgery simulators are available at more affordable prices than the ones depicted in Figures 6 and 7. Hoopes et al. (2021) introduce boxtrainer endoscopy simulators, which enable basic laparoscopic surgery procedures such as sutures, cuts, or staples, through real training instruments that interact with synthetic leather or other objects placed inside a cavity in a box. Figure 8 provides a few examples of such simulators.

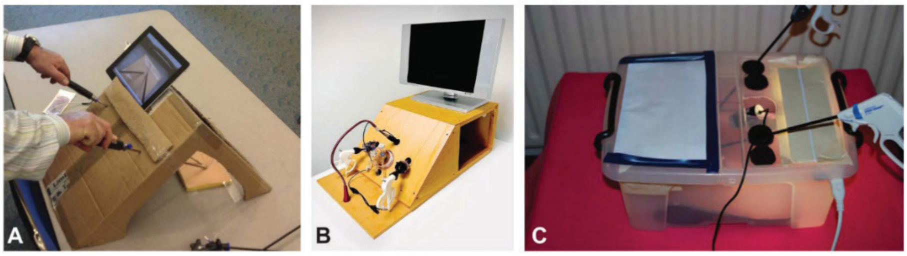

FIGURE 8. Box trainer equipment. Source: (Hoopes et al., 2021)

It's clear that the equipment presented by Hoopes et al (2021) is significantly less expensive than the equipment shown in figures 6 and 7. According to these authors, this equipment ranges between $70 and $2,000.00 in price abroad, not including hardware such as a tablet in some cases. However, it's important to note that there is a significant gap between this equipment and recent digital technologies that achieve high retention of knowledge, such as immersive virtual reality, which can be achieved with simpler and more affordable equipment.

3 METHOD

According to Santos (2018), Design Science is a research method used to develop and evaluate the efficiency and effectiveness of an artifact (product, service, or system) in solving a specific problem category. This method involves a literature review on the subject, which was presented in the previous section of this work. In this section, we present the development and testing of a training model for endoscopic surgeries using immersive virtual reality. The first step was to study alternatives for the model, followed by its development, and finally, a proof of concept (POC) was conducted with specialists in endoscopic surgery.

GENERATION OF ALTERNATIVES

The generation of alternatives for solving the problem was done in collaboration with the LAMPI team (Laboratory for Modeling, Prototyping and Innovation) of UFPR, which is part of this research project. The first step was brainstorming, where various ideas were generated and then filtered down into alternative solutions. During the meeting, various ways to solve the problem were proposed, such as: a virtual reality simulator suitable for smartphones, a simulator connected to computers, and an immersive virtual reality simulator, with an adapter that simulates endoscopic surgery instruments. made in 3D printing.

Based on the literature review and the availability of virtual reality equipments in the LAMPI, the selected alternative was the idea of the virtual reality simulator with an adapter for the Oculus Quest II for being the most suitable.

ARTIFACT DEVELOPMENT

For the development of artifacts, a complete measurement of endoscopic surgical forceps was performed to identify their components and functions. This dimensional analysis was performed with the help of measuring instruments such as a caliper and micrometer. This dimensional analysis can be seen in Figure 9.

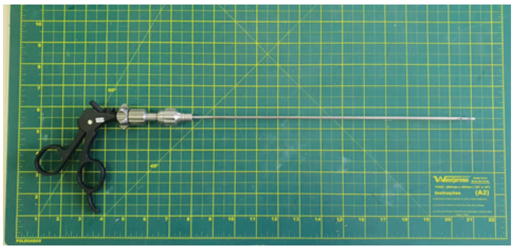

FIGURE 9. Measurement of the laparoscopy instrument (source: author).

The objective of replicating the same clamps used in current laparoscopic surgeries is to be able to adapt it to the virtual reality controls of the Oculus Quest II, to be able to make a very low-cost prototype. With the clamps and the control, we began to review possible forms of integration as shown in figure 10.

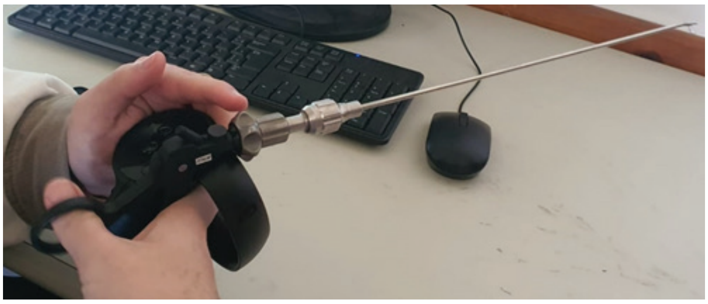

FIGURE 10. Revision to adapt clamp to Oculus control Quest II (source: by the author).

For the development of the proposed adapter artifact, a first 3D modeling was carried out in the Autodesk MAYA software, as shown in Figure 11.

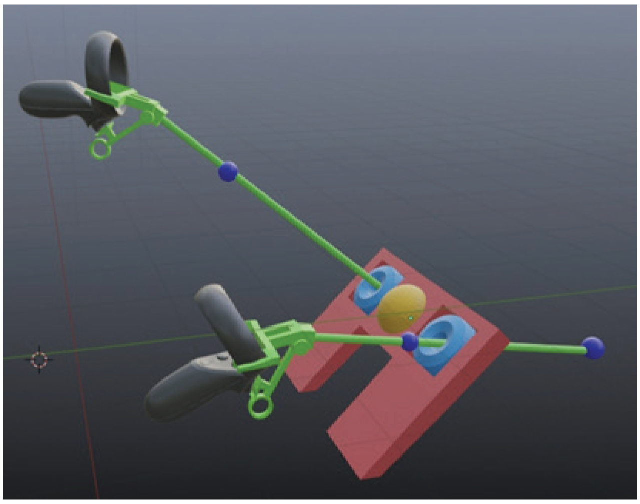

FIGURE 11. Initial model of 3D printed adapter mechanisms (source: author).

The aim of the first version of the adapter was to replicate all the functional and ergonomic features of the current endoscopic surgery simulator, as shown in Figure 7, while adapting the controls. This means that, for instance, when performing the opening and closing movement of the forceps, the adapter would press the corresponding button on the virtual reality controller through a 3D printed mechanism, reproducing the same action as in real life.

Figure 12 shows the first 3D printed prototype of the adapter, which incorporates the aforementioned adaptations.

FIGURE 12. First 3D printed prototype (source: author).

The initial prototype had some excess material, but it successfully demonstrated that the mechanism can activate the control button. Meanwhile, alongside the development of the 3D printed adapter, a virtual environment for endoscopic surgery was created using the 3DS Max modeling software. The operating room model was then rendered in the Unreal Engine software, and can be seen in Figure 13.

FIGURE 13. Operating room model (source: author).

After the 3D printed adapter and the virtual reality simulation were developed, an initial test was conducted with the LAMPI team from UFPR to evaluate the effectiveness of the system. The results of the test are shown in Figure 14, which demonstrates a user immersed in the operating room and observing the patient's digestive tract in virtual reality. During the pre-testing, users were able to visualize the environment and the digestive system, which is the first prototype of the type of endoscopic surgery developed. Feedback from users was noted and discussed as a team to further improve the VR system.

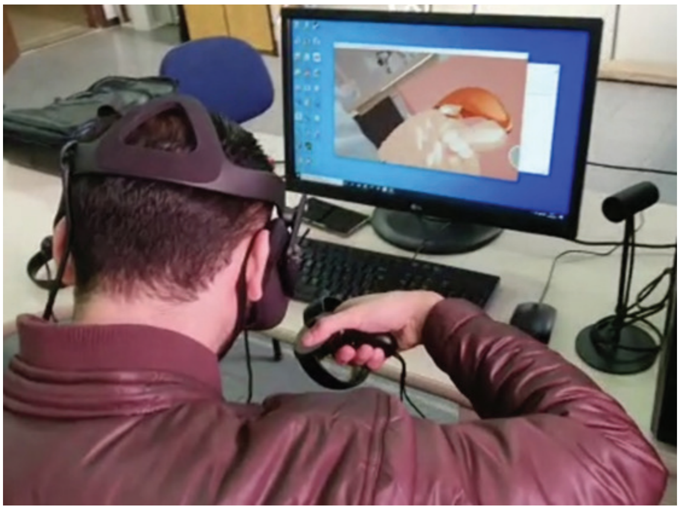

FIGURE 14. Pre-testing the system (source: author).

Based on the initial pre-tests, improvements were made at the interface level before conducting further testing. To ensure the development was as close as possible to reality, a test was planned with specialists in endoscopic surgery, which was called a Proof of Concept (POC) in the project. Two POCs were conducted, the first at the UFPR Clinic Hospital Complex, and the second at the IBEG (Erasto Gaertner Bioengineering Institute). Figure 15 presents the specialists doing the POC.

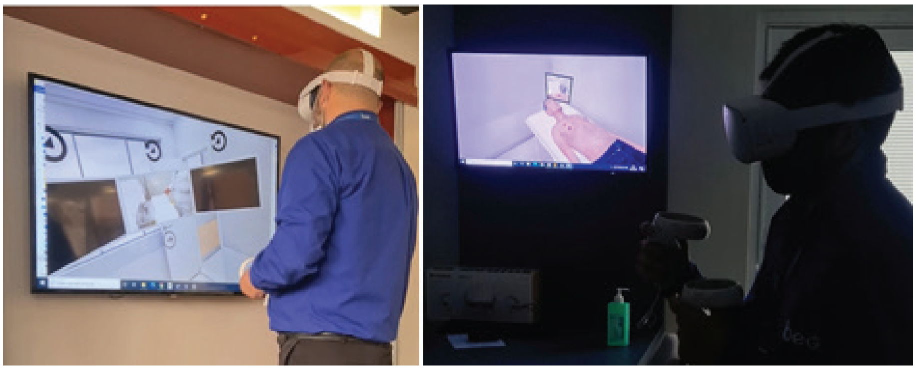

FIGURE 15. POC applications (source: author).

Following the applications of the developed prototype, improvement points were identified and classified into advantages and disadvantages of the proof of concept (POC).

Advantages:

- The estimated cost of the prototype at R$50,000 was deemed feasible by institutional managers.
- The level of immersion provided by the virtual reality simulation is highly realistic.
- The procedure guidance provided by the virtual assistant within the VR environment is effective and of high quality.

Disadvantages:

1. Haptic feedback needs to be enhanced to provide a more realistic tactile experience when interacting with virtual objects, such as organs, skin, needles, and other surgical instruments.
2. The audio quality of the virtual assistant and the sound effects for two instrument beats should be improved. It's worth noting that, in this POC, specific headphones for this context were not used, which could impact the overall audio experience.

The POC was well received by the project team and experts, acknowledging its limitations but recognizing its potential for improvement and applications. In addition, literature suggests the importance of developing an artifact that allows users to work similarly to the laparoscopic clamps shown in Figure 7. Khan et al. (2017) highlight that the use of instruments as a controller is very similar to reality as it limits the movements the surgeon can perform during the procedure. Furthermore, the literature emphasizes the need for a guide, similar to the one shown in Figure 11, to provide a more realistic experience. Ideally, this instrument would have significant haptic feedback to improve the surgeon's hand-eye coordination, depth perception, and ability to work in tight spaces with instruments that do not articulate intuitively. In future studies, it will be necessary to develop more questions for the virtual assistant to test the user and insert situations where the user must take action due to encountered problems.

4 Final Considerations

The field of endoscopic surgery training in Brazil is rapidly expanding, but the lack of effective and low-cost technology is a significant limitation for specialists in this area. However, the proof of concept developed in this study, along with interactions with various specialists, demonstrated a strong interest in immersive virtual reality training as a potential solution.

As demonstrated in existing literature, the use of virtual reality technology in medical training has yielded remarkable results. The NSLR and SLR conducted in this study were crucial in understanding the effectiveness of virtual reality through other studies. Additionally, the development of the artifact in this exploratory study helped to comprehend the complexity of these training programs and what factors should be considered. The results of the proof of concept have shown that immersive virtual reality training has the potential to be highly effective, offering a promising avenue for future research.

It is essential to develop workflows that accurately reflect real-world conditions and enable immersive virtual reality training in medical contexts, as this will facilitate testing with specialists in open and endoscopic surgeries, allowing for adjustments to be made to the training program as needed.

The proof of concept developed in this study demonstrated the potential of immersive virtual reality training in endoscopic surgery and identified the need for improvements, such as enhancing haptic feedback and improving the audio quality of virtual assistants and sound effects. The study also highlighted the promising possibility of conducting remote training sessions through multiplayer virtual reality platforms, which is particularly relevant given the ongoing global need to explore new methods of training.

For future studies, it is recommended to further explore and evaluate the effectiveness of immersive virtual reality training in endoscopic surgery. This could involve larger sample sizes and the inclusion of multiple institutions and specialties to ensure generalizability. Additionally, further development of the VR system to enhance haptic feedback and improve the audio quality of virtual assistants and sound effects could also be explored. Finally, more research is needed to examine the potential of conducting remote training sessions through multiplayer virtual reality platforms, as this could provide a more flexible and accessible option for training.

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