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Feasibility Analysis of an Immersive Network Laboratory as a Support Tool for Teaching Practices

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Abstract: *Background:*Information and Communication Technologies play a fundamental role in education, bringing real-world content closer to students and expanding learning opportunities. Immersive virtual laboratories stand out by enabling experimentation and overcoming the difficulties of accessing physical laboratories. Hybrid approaches have emerged to address challenges like space limitations, costs, and safety concerns in traditional laboratories by integrating immersive virtual environments with physical labs. The concept of the Metaverse is noteworthy for uniting physical and virtual realities, allowing user interaction through avatars. This combination aims to replicate the experience of in-person laboratories, fostering collaboration between students and teachers. The sense of presence in immersive virtual environments enhances realism, facilitating information processing during practical activities. This immersion can significantly benefit computing education, especially in laboratory-intensive subjects like Computer Networks that rely on physical equipment. *Methods:* In this context, this study aimed to investigate the use of immersive virtual environments as a support tool for teaching Computer Networks and to assess students' acceptance of these environments as aids in teaching-learning. The methodology applied involved four phases: (1) a Systematic Literature Review, which identified research gaps and opportunities for new pedagogical practices in computing education, as well as reviewing related works; (2) semi-structured interviews with Computer Networks teachers, to support the immersive environment's development; (3) modeling and development of the environment in the Metaverse; and (4) validation of environment acceptance using the Technology Acceptance Model (TAM) and the NASA Task Load Index. *Results:* The Systematic Review indicated that discussed pedagogical practices remain superficial, focusing on experimenting with existing environments and integrating the Metaverse with learning management systems (LMS). In Phase 2, the interviews revealed the importance of scalability in immersive virtual environments. The main goal of the interviews was to understand how teachers use computer and network laboratories, identifying the most-used equipment and content in teaching networks. This analysis was crucial for creating the interaction scenarios that guided the requirements of the NetVerse Edu platform. *Conclusion:* The acceptance results showed that students viewed NetVerse Edu as a valuable and effective tool for teaching networks, highlighting its ability to facilitate familiarization with equipment and understanding technical concepts. Regarding workload, the immersive environment proved challenging, requiring a high level of cognitive effort, but provided a productive experience without significant discomfort or frustration.

Keywords: Virtual Reality, Metaverse, Computer Networks, Distance Learning

1 Introduction

Information and Communication Technologies (ICTs) have played a fundamental role in education, providing students a closer connection to the real world through educational software and tools (Wagner et al., 2013). The increasing importance of ICTs was consolidated with the publication of the National Common Curricular Base (BNCC), which recognizes technology as an essential element for building knowledge in contemporary education [**?**]. Within this technological context, tools such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) stand out, especially with the popularization of the concept of the Metaverse. Introduced by Stephenson [1992], the Metaverse represents an online three-dimensional environment where physical and virtual realities converge, creating immersive spaces for social and economic interactions [López *et al.*, 2022] and [Ritterbusch and Teichmann, 2023]. This technological evolution, which was particularly strengthened during the social distancing period imposed by the pandemic, enabled companies like Meta (formerly Facebook) to invest in creating these immersive virtual environments [Meta, 2021].

Research indicates that these environments can potentially transform teaching-learning, offering more immersive and interactive pedagogical experiences [Dwivedi *et al.*, 2022]. Recent studies show the growing application of these technologies across various fields, from natural sciences to the humanities [Tlili *et al.*, 2022] . The capacity of Virtual Worlds (VW) to simulate fundamental human interactions [Tibúrcio *et al.*, 2022] reinforces their emerging role in education, as well as in sectors such as health and entertainment. The use of immersive virtual environments has gained relevance in various educational fields, particularly in engineering, one of the most researched areas about Metaverse use in education [Tlili *et al.*, 2022]. Traditionally, simulation has been an essential tool in engineering and computing education, enabling students to develop practical skills in a controlled environment. However, with the advent of immersive environments, these simulations can offer a more realistic and engaging experience, enhancing the sense of presence and providing a shared learning experience [Schaf *et al.*, 2012].

The growing challenge of maintaining physical laboratories, mainly due to the high construction, maintenance, and scalability costs, has created the need for new approaches [Alsaleh *et al.*, 2022]. In response to these limitations, researchers suggest combining pedagogical activities in physical laboratories with immersive virtual environments as a hybrid solution that meets students' increasing demand and logistical constraints. For engineering and technological courses, laboratories remain a fundamental part of training, and virtual environments emerge as a promising alternative to complement this need [Schmitt and Tarouco, 2008]. The use of immersive virtual laboratories, especially in Distance Education (DE) courses, can also reduce access barriers faced by students who often cannot attend in-person laboratories due to geographical or infrastructural limitations. These laboratories allow the consolidation of practical concepts and promote collaboration and communication between students and teachers in a virtual environment [Amaral *et al.*, 2011].

Given this context, the present study sought to investigate the feasibility of an immersive virtual laboratory for teaching Computer Networks. The general objective of this study was to develop and evaluate the feasibility of an immersive virtual laboratory as a support tool for introductory practical teaching in Computer Networks. To achieve this objective, the following specific objectives were defined: to investigate the use of virtual environments in education, highlighting their advantages, disadvantages, benefits, and technological resources used, as well as the challenges and limitations involved; to define the content, pedagogical practices, practical activities, and equipment used in Computer Networks courses to be tested in the virtual environment; and to perform a benchmark on engines, tools, and platforms focused on immersive education in the context of the Metaverse.

This article is organized into five sections: Section 2 discusses related work. Section 3 presents the methods used in the study, and an immersive virtual environment is developed. Section 4 presents the obtained results. Finally, Section 5 provides the conclusions.

1.1 Ethical issues

This study was conducted with ethical research principles, ensuring voluntary participation, anonymity, and data confidentiality. All participants were adults and invited to participate in the study based on free acceptance. Before participating in interviews and user evaluations, they were informed about the study's objectives and procedures. Participation was voluntary, and they had the right to withdraw without consequences. All collected data were anonymized and securely stored to protect participants' privacy. No personally identifiable information was recorded, and the results were analyzed in an aggregated manner.

Considering the immersive nature of the virtual environment used in the study, measures were taken to ensure participant well-being. Clear instructions on using the system were provided, and optional breaks were allowed during the activities to minimize discomfort. Participants were encouraged to report discomfort, and technical support was available throughout the study.

This research was not submitted to the Ethics Committee as it complies with the sole paragraph of Article 1 of Resolution 510/2016 of the Brazilian National Health Council. According to item VII, research that theoretically deepens emerging situations in professional practice is exempt from ethical review, provided that participants cannot be identified. Furthermore, the Brazilian National Research Ethics Commission defines this type of study as a one-time, verbal or written consultation that collects assessments and perceptions without the possibility of identifying respondents, which applies to this research.

2 Related Work

In the literature, various studies address using the Metaverse in computing education, focusing primarily on programming instruction and creating virtual environments. Nunes *et al.* [2017] explored the integration of a Learning Management System (LMS) with a Virtual World (VW), developing a virtual environment in OpenSim and linking it to Moodle through the Sloodle tool. The case study was conducted in an Algorithms and Programming course within a Computer Engineering program, validating the interaction between these environments.

Similarly, Wagner *et al.* [2013] proposed a Metaverse environment to support distance technological and vocational courses, including Massive Open Online Courses (MOOCs). The environment, created on the OpenSim platform and integrated with Moodle through Sloodle, allowed students to explore virtual spaces, interact online, and review concepts. Díaz (2020) presented a VW as a pedagogical support tool at the University of Cundinamarca, aiming to enhance the training of Systems Engineering students and develop digital competencies among teachers. The VW developed on the OpenSim platform facilitated remote classes accessible via the web and mobile devices. They were well-received by students in terms of interaction and navigation, creating a more dynamic learning process.

Another example is the work of Sebastien *et al.* [2018], who proposed a VR environment named Immex, simulating the University of La Reunion campus. Using the Unity platform, the environment provided users with an immersive first-person experience. The evaluation, conducted with master's students in Computer Science, focused on the platform's usability and acceptance, yielding positive feedback. Jeong *et al.* [2022] proposed a shared virtual campus among 15 partner universities to overcome physical barriers and optimize resources. Using the VirBela platform, the campus included laboratories and exhibition rooms. It was integrated with the LMS of the participating institutions, offering an innovative solution for teaching in a collaborative environment.

One of the methodological steps of this research framework was a Systematic Literature Review (SLR) covering the period from 2012 to 2022, aiming to identify empirical studies on using immersive virtual environments in education. The SLR investigated the state of the art regarding immersive virtual environments in various educational domains, analyzing the leading platforms, the technological resources em-

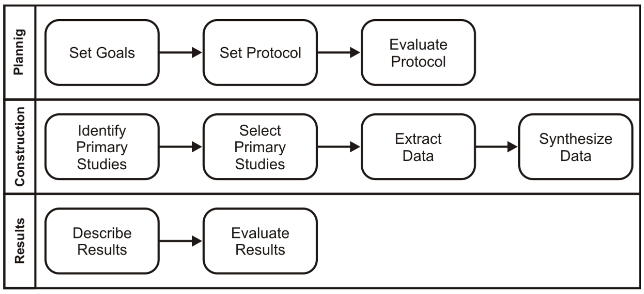

Figure 1. Phases of the Systematic Literature Review

ployed, and the limitations and challenges encountered. The process was conducted in three phases: Planning, Construction, and Results, as illustrated in **Figure 1**. The objective, research questions, and the SLR protocol were defined in the planning phase. During construction, studies were selected and analyzed based on a search string applied to scientific databases [**Table 1**], following established inclusion criteria. In the final phase, the results were tabulated and classified according to the frequency of the research questions in the selected articles. The inclusion criteria considered: (i) full-text

Table 1. Search string

((”education” OR ”learning” OR ”teaching”) AND (”metaverse”))

access via the CAPES Portal, (ii) absence of duplicates, (iii) publication between 2012 and 2022, (iv) language in English or Portuguese, (v) description of the platform used or developed, and (vi) application of the Metaverse in the teaching-learning process. The automated search in digital databases resulted in 516 articles indexed on the Parsifal platform for relevance analysis. The libraries used were ACM Digital Library (103), IEEE Xplore (77), SBC OpenLib (3), Science Direct (21), Scopus (197), and Wiley (115). Researchers discussed the results in meetings during the Data Extraction and Synthesis phase. The complete list of included articles is available at https://tinyurl.com/buscaartigos. Detailed information on the SLR can be found in [Vieira and de Medeiros, 2023].

Analysis of the accepted studies revealed that most focus on learning VR and programming. However, studies need to address Computer Network teaching directly through virtual environments. According to Alpala *et al*. [2022], the sense of presence in immersive environments can enhance information processing, suggesting that Computer Networks education could benefit significantly from this technology. The SLR conducted, along with the study by Tlili *et al*. [2022], indicated that most research focuses on higher education, underscoring the Metaverse's potential to overcome limitations and inefficiencies found in both traditional face-to-face learning and online education with non-exploratory interactions. Tlili *et al*. [2022] also highlighted the lack of research or documented experiences exploring the Metaverse in the education of People with Disabilities (PwD). This gap was confirmed by our SLR, which identified no studies on accessibility in educational immersive virtual environments.

When comparing the technologies cited by Tlili *et al.* [2022], growth was observed in the use of game engines like Unity and Unreal Engine for developing immersive virtual environments, along with the increasing adoption of web-accessible Metaverse platforms such as Spatial.io, Zepeto, and VirBela. Tlili *et al*. [2022] suggested that future studies explore the application of lifelogging technologies in Metaverse education and IoT devices connected to virtual environments to enable interaction with the real world. Another avenue for research would be the development of soft skills by students within immersive virtual environments, given that some studies report opportunities for interaction and collaboration with people from different backgrounds and cultures, as well as the resolution of complex and creative tasks. They also emphasize the need for research focused on the inclusion of PwD.

The complexity of virtual environments and the difficulties teachers face in utilizing the Metaverse were identified as limitations in the studies analyzed, such as in the work by Nunes *et al*. [2017] and Díaz [2020]. Although there is research exploring the use of the Metaverse in education, studies specifically addressing the teaching of Computing subjects in immersive environments remain scarce. This opens possibilities for future research, whether by adapting existing virtual environments or creating new, customized spaces for distance, hybrid, or in-person courses. Pedagogical practices focused on computing education, as discussed in the analyzed articles, are still superficial. It is noted that most studies concentrate on experimenting with existing environments, integrating VWs with LMS platforms, and identifying challenges related to Metaverse use in education. Regarding Computing subjects, most studies focus on learning VR and programming. Alpala *et al*. [2022] highlight that the sense of presence in immersive environments can provide a more realistic experience, which enhances information processing during practical activities.

The study by Richardson-Hatcher *et al*. [2014] raises a relevant issue about the cognitive load imposed on students in virtual environments. By applying cognitive load theory principles in the design of virtual environments, the researchers sought to improve the usability of these tools. Thus, examining the psychological implications of using immersive environments in education is essential, especially regarding the cognitive load on students and teachers. The analysis of related work demonstrated a demand for increased investment in research to create more accessible and personalized immersive virtual environments for Computing. Additionally, it is crucial to develop more profound pedagogical practices that effectively use these environments' resources for teaching and learning specific Computing content.

3 Method

To achieve the objectives of this research and answer the questions raised, a methodological approach was adopted, divided into four distinct phases. As described in Section 2, Phase I involved conducting the SLR. Phase II consisted of semi-structured interviews with professors in Computer Networks. The information collected was analyzed through open coding, which allowed insights to be extracted to define interaction scenarios and requirements for developing the NetVerse Edu immersive virtual laboratory. As emphasized by Galvez *et al*. [2022], the participation of stakeholders, such as professors, in various design and development phases is crucial for successful educational immersive environments. This stage sought to understand the use of physical equipment in didactic activities and define the content and interaction level needed to create the immersive virtual laboratory.

In Phase III, the environment in the Metaverse was modeled and coded. This environment included an auditorium, a thematic room with network equipment, a quiz on Computer Networks, and a laboratory for IP addressing activities. Free 3D objects available on the Sketchfab platform [Sketchfab, 2023] were used to create virtual spaces, and they offer resources for modeling in AR and VR projects. The development of the environment was based on the semi-structured interviews from Phase II, analysis of teaching plans, and benchmarking of network simulators.

Finally, in Phase IV, a feasibility study was conducted to evaluate the acceptance of the immersive virtual environment among professors and students, using the Technology Acceptance Model (TAM) proposed by Davis [1989]. This model considers that Perceived Usefulness (PU) and Perceived Ease of Use (PEOU) determine technology acceptance and intent to use. Structured questionnaires based on TAM, adapted to the Metaverse context, were applied to collect data on the acceptance of the environment. Additionally, a workload test was conducted using the NASA Task Load Index (NASA TLX) methodology to assess students' perceived workload using the immersive virtual environment.

3.1 Data Source: Semi-Structured Interviews, Teaching Plans, and Network Simulator Benchmark

To guide the development of the virtual platform, semi-structured interviews were conducted with faculty members from the IFPB João Pessoa Campus, who teach courses related to Computer Networks in technical, undergraduate, and graduate programs. These faculty members are referred to as professor 1, professor 2, professor 3, and professor 4. The semi-structured interview technique, a qualitative data collection method, combines predefined questions with the flexibility to explore emerging topics and delve deeper into responses. The interviews were conducted between November 10 and 20, 2023, via Google Meet, recorded, and transcribed with the participants' consent.

The interview script contained nine guiding questions related to teaching Computer Networks: (i) frequency of laboratory use for Computer Networks; (ii) subjects involving the use of the lab; (iii) content covered in practical lessons; (iv) equipment and resources used; (v) software used to teach networking concepts; (vi) contribution of the software to teaching; (vii) strategies used during the pandemic for remote lab activities; (viii) challenges faced in using the labs; and (ix) suggestions for improving the teaching-learning process in networking contexts. The script served as a guide, allowing the interviewer to adapt questions and explore in-depth topics based on responses. The guiding questions and the outcomes of the interviews led to the development of codes used for analysis through open coding, the initial data analysis stage, as described by Hoda *et al*. [2012]. The data were categorized into eight codes: (i) Frequency of lab use; (ii) Courses taught; (iii) Topics covered; (iv) Equipment and physical resources; (v) Software used; (vi) Remote lab practices; (vii) Challenges faced; and (viii) Suggestions for improvements.

The interviews revealed that subjects such as Fundamentals of Networks and Introduction to Computer Networks are shared across programs, covering primary and introductory concepts in technical, undergraduate, and graduate courses. To corroborate these observations, a document analysis of the teaching plans for the courses in Computer Science, Network Systems, Technology in Internet Systems, and the Master's Program in IT was conducted. These plans are available on the IFPB João Pessoa Campus student portal. Additionally, the interviewed professors highlighted the use of network simulators. Simulators like NS-3, GNS3, Mininet, and Packet Tracer were tested to evaluate how each tool presents network scenarios to users, serving as a foundation for developing the initial activities on the platform created for this research. These tests and analyses contributed to specifying the interaction and functionality requirements for the platform, guiding the development of the proposed immersive experience. The open coding process helped organize the information to support the creation of interaction scenarios in the NetVerse Edu platform.

Code 1: Frequency of Lab Usage: This code explored the frequency of lab usage for educational activities, examining how often these spaces are employed for teaching Computer Networks and the demand from faculty for these environments. **Table 2** presents excerpts related to this code.

It was observed that the use of labs is essential for the interviewed professors. While some courses are specifically directed toward lab sessions, others predominantly use the classroom and depend on the availability of labs for practical activities. The data collected highlighted the need for high availability of the platform proposed in this research and an environment that caters to both classroom and lab requirements.

Code 2: Disciplines Taught: This code aimed to identify the courses that cover Computer Networks and analyze the relationship between these courses across technical, undergraduate, and postgraduate programs. **Table 3** presents the excerpts obtained related to this code.

The data analysis shows similar disciplines across the technical, undergraduate, and postgraduate courses, all addressing fundamental concepts of computer networks. This highlights the need to develop a platform capable of supporting these disciplines at the institution's educational levels.

Code 3: Covered Content: This code aimed to identify common topics across various disciplines and course levels to define the potential content to be initially addressed on the platform. **Table 4** presents the excerpts related to this code.

The data reveals that foundational content on Computer Networks is covered across various educational levels. Therefore, there is a clear need to develop a platform that can be used as a supportive tool for teaching computer networks, addressing the shared content across technical, undergradu-

Table 2. Excerpt from interviews with teachers and Teaching Plans regarding the frequency of laboratory use for teaching Computer Networks.

Source	Excerpts
Interview: Professor 1	"[…]The computer networks course already has a dedicated convergent networks room, allocated specifically for all theoretical and practical classes... [...] Where I need a bit more flexibility is with the Internet Systems classes, as the curriculum plan is somewhat more limited. I alternate between the classroom and the lab, usually weekly, depending on availability. All content is taught in the lab for both the foundational courses in computer networks at the higher education level and for the technical course in computer science, except for Internet Systems. In Internet Systems, we have to split the time because the infrastructure—let's say, the guaranteed room allocation—is not always ensured."
Interview: Professor 2	"[...]All my classes take place in computer labs. We have a specific lab for the course, called the convergent networks lab, but I don't teach in that lab. Since my course involves working with virtual machines, any lab with good computer hardware works. So, depending on the class size and the operating system requirements, I use any available lab, but all my classes are conducted in labs."
Interview: Professor 3	"[…] In every class."
Interview: Professor 4	"[…] 100%, I only teach in the lab."
Teaching Plan: Integrated Technical in Computer Science	"[…] Practical lessons in the lab. Optional use of 20% of the class time for distance learning."
Teaching Plan: Bachelor of Technology in Computer Networks.	Plan 33 hours of practical class time.

ate, and graduate courses in an immersive way.

Code 4: Equipment and Physical Resources: This code aimed to analyze the physical resources commonly used by teachers and how these resources are employed in the teaching and learning process. The main objective was to determine which devices would be initially modeled in the virtual immersive environment to be developed and the interactions with these resources on the platform. **Table 5** presents the excerpts obtained related to this code.

It was observed that although some disciplines do not use physical lab resources, they rely on network scenario simulations through software. Therefore, the simulation of computer network scenarios in the immersive virtual environment could meet the needs of both disciplines that utilize physical labs and those that depend solely on simulations in the teaching and learning process.

Code 5: Software Used: This code sought to identify the software tools employed in teaching Computer Networks and how these resources support the teaching and learning process. The analysis aimed to understand how these tools present data to users, with the goal of creating a more user-friendly interface for the immersive virtual environment. The intention was to leverage the simulation environments' learning curve, basing the interface on the software identified. **Table 6** presents the excerpts related to this code.

The data analysis revealed that network simulators are the primary software tools for teaching computer networks. It was observed that there is a need to develop an immersive virtual environment that enhances the simulation level, allowing users to simulate network scenarios and manipulate devices within the virtual environment.

Code 6: Remote Laboratory Practices: This code aimed to understand how teachers adapted laboratory practices for remote learning, using the COVID-19 pandemic as a reference. Before this period, many courses did not include remote learning hours and had to be adjusted due to the social distancing imposed by the pandemic. **Table 7** presents the excerpts obtained related to this code.

Upon analyzing the obtained data, it was concluded that network simulators supported remote teaching. It became evident that there is a need to develop an online, immersive, multi-user, and collaborative virtual environment where users can simulate computer network scenarios and share resources and experiences.

Code 7: Challenges and Difficulties: This code aimed to understand the main difficulties and challenges faced by teachers when using laboratories for teaching computer networks. **Table 8** presents the excerpts related to this code.

It was observed from analyzing the data that teachers' main difficulties are related to students' access to equipment, infrastructure, and the level of access to laboratory resources. In response to these challenges, there is a need for initial content related to computer networks, greater access freedom to equipment, and the scalability and adaptability of the immersive virtual environment.

Code 8: Suggestions: Considering the challenges and difficulties mentioned in the previous code, this question aimed to assess the teachers' suggestions for mitigating or overcom-

Table 3. Excerpts from interviews with teachers and Teaching Plans regarding the subjects that involve using laboratories for teaching Computer Networks.

Source	Excerpts
Interview: Professor 1	"[…]in all three programs, the course is called Fundamentals of Computer Networks, in all three programs: both in the bachelor's in computer networks, in the bachelor's in internet systems, and in the computer technician program."
Interview: Professor 2	"[...]currently, I teach three courses in the computer networks program: one in the first semester, called Introduction to Open Systems; another in the fifth semester, called Administration of Proprietary Systems; and one in the sixth semester, which is the final semester, called Computer Network Projects. Essentially, that's it."
Interview: Professor 3	"[…]in the networks program, there is a course called Fundamentals of Computer Networks in the first semester. For this course, I primarily used a simulator. In the second semester, there is a course called Switching Technologies, where I used actual equipment since we have a lab with switches and routers. In the third semester, I teach a course on Routing, where I also used real equipment, specifically routers."
Interview: Professor 4	"[…] Currently, I am teaching the Fundamentals of Networks course in the Electrical Engineering program, the Virtualization course in the Computer Networks program, and two other courses, Virtualization and Performance Evaluation, which are part of the technologist program in Computer Networks. Additionally, I am teaching the Fundamentals of Networks course for Electrical Engineering and a Computer Networks course in the master's program."
Teaching Plan: Integrated Technical in Computer Science.	Fundamentals of Computer Networks. General Objective: Understand the operation of a local area network (LAN). Specific Objectives: Understand the history of networks and the motivation for their emergence; Classify networks under various parameters; Understand and differentiate the OSI/ISO Reference Model and the TCP/IP architecture; Identify the most commonly used standards in local networks today; Understand the application, transport, network, and link layers; as well as identify their main protocols.
Teaching Plan: Internet Systems Technologist	Fundamentals of Computer Networks.
Teaching Plan: Bachelor of Technology in Computer Networks.	Fundamentals of Computer Networks. General Objective: Present the architecture, structure, functions, components, and models of computer networks.
Teaching Plan: Professional master's in information technology.	Introduction to Computer Networks.

Table 4. Excerpts from interviews with teachers and Teaching Plans regarding the contents covered while using laboratories for teaching Computer Networks.

Source	Excerpts
Interview: Professor 1	”[…] Fundamentals of networks for the higher education course in computer networks and fundamentals of networks for the technical course in computer science, the syllabus is the same, the content is the same. We cover everything from the introduction, what the internet is, a bit of history, how computer networks have evolved, going through the physical layer, data link layer, network layer, transport layer, application layer, and we adopt this methodology, this type of teaching, bottom-up, meaning from the lower layers to the higher layers.”
Interview: Professor 2	“[...] The project is an integrative discipline of the course, so what I do, my idea, is to validate all the experiences they had separately throughout the course. So, the solutions encompass network fundamentals, network security, structured cabling, network services in Linux, network services in Windows, wireless networks, protocols such as DNS, HTTP, proxy, all these concepts, and network management as well. These are the concepts they acquire throughout the course, and the idea is to build a network scenario and have them integrate the solutions they’ve learned as knowledge in each of the course disciplines.”
Interview: Professor 3	“[...] Look, IP addressing, IPv4 addressing, IPv6, TCP protocol, UDP, VLAN. Let me remember here, let me think… Ethernet protocol, ICMP protocol. Anyway, the TCP/IP protocols, not too deeply, in this first-period discipline it was more of a general overview of each protocol. The student will dive deeper into them in the subsequent periods.”
Interview: Professor 4	“[...] In the computer networks course that I currently teach for the electrical engineering course and for the master’s in IT, I cover a review of the theoretical foundation concepts of computer networks, from the segmentation in layers, the use of layers, service models, the TCP/IP model, physical layer, data link layer, network layer, addressing protocols, IP protocol, routing protocols, all these contents in the networks or fundamentals of networks discipline that I teach respectively in the master’s and in electrical engineering.”
Teaching Plan: Integrated Technical in Computer Science.	Introduction to computer networks, History and evolution, Classification of networks, Topologies and connectivity, TCP/IP model, OSI model.
Teaching Plan: Internet Systems Technologist	History, definitions, and classifications of computer networks. OSI and TCP/IP models: proposals and layers. Physical layer: functions and transmission media. Data link layer: functions and protocols. Local area network standards. Network interconnection devices. Network layer: functions and protocols. Mobile networks.
Teaching Plan: Bachelor of Technology in Computer Networks.	Network access: Physical layer protocol, Network communication medium, Data link layer protocols, Medium access control; Network layer: Network layer protocols, Routing, Routers, Configuring a router; IP addressing.
Teaching Plan: Professional master’s in information technology.	Fundamentals of computer networks. Challenges for research and innovation in: network traffic analysis, quality of service, traffic engineering, switching and routing, network management, wireless networks. Current technologies of high-speed network infrastructure. Aspects of architecture and traffic for Internet of Things applications. Data center network architecture. Software-Defined Networks. High availability and Cloud computing infrastructure. Network security.

Table 5. Excerpts from interviews with teachers about the physical resources used during the use of laboratories for teaching Computer Networks

Source	Excerpts
Interview: Professor 1	"[…] The convergent networks laboratory, just to complement, is where everything is. It has everything, including the physical part, cabling, classes, in short, it's where everything is. However, as it's a fundamentals course, we don't work directly with the switches, the physical switches, or the physical routers. We work entirely within the simulator. Only the cabling part, the introductory part, is done so the students can see how RJ45 cabling is done, our famous twisted pair."
Interview: Professor 2	"[...] In the specific case of the project, only the computers, what is on the computers is enough. We have the hypervisors, the VM and VirtualBox, we have Visio as I mentioned, there is web access, so everything they need is on the common desktop computers… […] So the highest level they get to practice is through simulations."
Interview: Professor 3	"[…] At the João Pessoa campus, we have a laboratory called the convergent networks laboratory, and there we have two racks of Cisco switches and routers. So, we had workstations, which we called islands, and at these workstations, we had outlets that provided access to a Patch Panel in the rack. Each group, with four students per island, had access to the rack. I divided the switches, I allocated one switch for each group, and we divided the access so that each group could configure the equipment at their own workstation. They would inevitably need to go to the rack to make a physical connection, but basically, all the practical work took place at the workstation itself. There was no need for everyone to be standing at the rack, especially since there were too many people."
Interview: Professor 4	"[…] Physical resource, my subjects are highly dependent on the laboratory itself, on the machines in the laboratory, so that students can execute virtualization, set up environments, and I usually work with the Linux operating system and various tools on top of this system. So, in order not to interfere with the machines in the lab, we work a lot with virtualization. […] For the subject of network fundamentals in electrical engineering, I currently teach in the convergent networks lab. And there, we have a great infrastructure with network interconnection equipment, such as routers, switches, racks, and cabling, which allows us to perform some practices on physical equipment, not virtualized."

Table 6. Excerpt from teacher interviews about the software resources used for teaching Computer Networks and how these tools assist the teaching-learning process.

Source	Excerpts
Interview: Professor 1	"[…] The Packet Tracer. Usually, I provide the ready-made environment, or when I don't provide the ready-made environment and ask the students to do some kind of configuration, I give them half of the environment. I do it in class, I tell them the environment is this, and half of the environment is this. Actually, it's not even half; I do 1/3 of the environment with the students, and leave the rest for them to complete, which I then assess. […] Abstraction, we can abstract all the handling of cabling, the part of having to connect a computer, having to connect a switch, having to connect a router to the rack, and handling the rack. Also because you can't have more than three or four people close to the rack, as there is a physical limitation of people at the same time."
Interview: Professor 2	"[...] the Packet Tracer. In my case, it's more about the scenario. Since the scenario is an internal company network, it ends up being enough to conduct experiments validating network services using the hypervisor with the virtual machine. Occasionally, some simulation of local traffic showing only the configuration in the Packet Tracer, like configuring a VLAN for a switch or a static route, but all of that at the Packet Tracer level. […] They are fundamental, mainly the hypervisors, because we can create and reproduce an entire network environment for each student."
Interview: Professor 3	"[...] Cisco Packet Tracer, we used some software to analyze, for example, Wireshark to analyze packets, and the other applications were the ones inside the switch or router itself, the proprietary Cisco applications that are the protocol implementations. [...] it helps in reinforcing the theory. I was a student in the course, and when I was a student, we didn't have access to the equipment, there were no devices, it was all on the blackboard. So, we knew the theory, but we didn't have the practice."
Interview: Professor 4	"[...] Virtual machine manager, to manage VMs in VirtualBox, I use Docker a lot, containers, KVM, and VirtualBox, as I mentioned, NS3, which is a network simulator, GNS3, which is another one, Packet Tracer, as I mentioned, and Mininet too, to emulate a network on a single machine. Anyway, these are basically the ones that come to my mind now. [...] I can represent a network scenario, for example, involving a variety of devices. I can simulate, for instance, an IoT network without necessarily having an IoT device. I can simulate an SDN network without necessarily having a set of switches to do this physically."

Table 7. Excerpt from interviews with teachers about adapting laboratory practices in distance learning for Computer Networks.

Source	Excerpts
Interview: Professor 1	"[...] The classes were 100% remote. I used both WireShark, Packet Tracer, and the Windows Resource Viewer."
Interview: Professor 2	"[...] I talked about the DNS protocol, the related concepts, so there was this presentation moment, and then I presented the scenario: we're going to need a client, we're going to need a server, and I started making the configuration, narrating this moment."
Interview: Professor 3	"[...] During the pandemic, I was away for my doctorate. [...] Nowadays, there are more simulators, emulators, you have Mininet, a range of things, things that didn't exist before. When I was a student, these didn't exist, so it was more difficult. I think that despite an online course, not having access to equipment may be a difficulty, but with the simulation and emulation environments we have today, I think it's already a significant improvement."
Interview: Professor 4	"[…] It was quite complicated because I had to adapt my class, which I used to run on a machine in the laboratory, to run on the students' equipment at home, which is usually more modest, with less processing power and less memory. So, for me, it was really difficult; I consider that I couldn't extract the most from my courses due to this infrastructure issue. So, what I did was set up a more powerful scenario at my house, and many of the things I wanted them to do in the laboratory—practicing, adjusting, configuring—I did on my own machine and showed them how I did it."

Table 8. Interviews with teachers about the challenges and difficulties encountered using laboratories for teaching Computer Networks.

Source	Excerpts
Interview: Professor 1	"[…] there is the issue that many students are not very well-off and have never had much contact with computers; they usually use cell phones, but generally don't have much contact with computers. We have to lower the level a bit and give a small introduction to computers."
Interview: Professor 2	"[…] what happens is that we have computers that were purchased long before the pandemic, I think the last government purchase policy was in 2016 or so. These machines have reasonably good hardware, but they rely on HDDs, so the performance is very compromised. […] I like to experiment, I think we learn by experimenting, I like to have the student experiment, not in a loose way, but in a guided way."
Interview: Professor 3	"[…] The difficulties we face are related to electrical infrastructure and physical space. Our campus is quite old, and sometimes, for example, when there is a power outage, or when the capacity that was planned for the laboratory is exceeded, the electrical network can't handle it and shuts down."
Interview: Professor 4	"[…] Many times, it's even understandable for the people who organize the laboratories and do the maintenance. There is a department that handles the maintenance, and often they have their own policies about what can and cannot be installed, how the machines should be configured. And these configuration policies often clash with some things I need for my class."

ing these obstacles. This code aimed to identify ways to address these needs through the immersive virtual environment proposed in this research. **Table 9** presents the excerpts related to this code.

It identified the need for an adaptable immersive virtual environment that can serve as a supportive and introductory tool in the teaching and learning process of Computer Networks. The data analysis highlights the importance of scalability in the immersive virtual environment and the freedom of access and configuration of equipment within the learning environment. The interviews were conducted to understand how teachers use computer and network labs, identify the equipment used in the teaching and learning process, and the content typically covered in computer network education. In addition, efforts were made to understand the difficulties encountered in using these labs. The analysis of these data served as the foundation for creating interaction scenarios that represented the interaction requirements for the platform developed.

3.2 Interaction Scenarios

Elaborating interaction scenarios is fundamental for capturing human practice as it occurs in the present, providing valuable insights that highlight requirements and limitations in developing new artifacts. According to Falcão and Gomes [2006], a scenario consists of three main elements: environment, actors, and script. The script describes a sequence of actions and events, representing the actors' activities throughout the episode, the results of those actions, and the changes in the environment. These events can facilitate, obstruct, or be neutral about the actors' goals. Thus, the construction of interaction scenarios not only documents the current behavior of users but also anticipates how future systems might be developed to meet their needs better and overcome existing challenges. Such scenarios are crucial for identifying potential problems and opportunities and guiding the development of effective technological solutions suited to the context of use. In this sense, after analyzing the data collected through open coding, the interaction scenarios for the immersive virtual environment of this research were specified. These scenarios allow students to practice concepts related to Computer Networks and engage in an activity focused on IP addressing, a topic covered in several network-related courses in the programs analyzed. During the specification of these scenarios, in addition to analyzing data obtained from interviews and the benchmarking of network simulators, a creative process was incorporated to describe the needs the virtual platform should address in detail.

Interaction Scenario 01: User Identification

Actors: Teachers and students of information technology courses with disciplines in computer networks.

Environment: An immersive and adaptable virtual environment designed for educational activities in computer networks.

Script: Upon accessing the immersive virtual environment through the headset device's app menu, the user is directed to an identification area. An identification option is provided in this area, where the user must interact with the laser pointer to enter their name. The user directs the laser from the headset controller to select the option. Next, a field is presented for the user to type their name; a virtual keyboard is displayed using the laser and pressing the controller button. The user interacts with the virtual keyboard using the laser to input their name. After typing their name, the user closes the virtual keyboard, making the option to enter the virtual environment available. The user also has the option to return to the previous screen if necessary. The user is directed to the starting room, a welcome area, by selecting the option to enter.

Interaction Scenario 02: Welcome Room and Instructions

Actors: Teachers and students of information technology courses with disciplines in computer networks.

Table 9. Excerpts from teacher interviews on suggestions for addressing the challenges and difficulties in using laboratories.

Source	Excerpts
Interview: Professor 1	"[…] FIC course, both for elementary school students and for those who are entering, actually, this needs to be for students who are enrolling. An FIC course introducing computers, the basics of the basics, about what the internet is, what a browser is, what the internet is, active devices, routers, and end devices."
Interview: Professor 2	"[...] I spoke with the support staff and they are planning an upgrade, at least replacing the HD with an SSD, to give the equipment a longer life and consequently provide better support for the course. So I always highlight this reality, that within an organization, the employee, the collaborator, the administrator, must face solutions. Some students come to me and ask if they could bring their super notebook with an SSD, 16GB of RAM, etc., and I tell them they can bring it, but they will take the exam on the IF computer, because there they will encounter solutions with limitations. The idea is not to create a hostile environment, but a realistic one. These difficulties are part of the real world."
Interview: Professor 3	"[...] it is a specific issue with our infrastructure. Perhaps in a newer campus, this wouldn't happen."
Interview: Professor 4	"[...] I think there are some possibilities, for example, thematic laboratories. I think there could be a computer networks lab where, for example, it would be possible for teachers to change the machine configurations according to the class they need, not a fixed setup with a password where the teacher doesn't have the freedom to install software or things like that. I think this would be an alternative. Another option is the use of technology itself. As I mentioned, I have a project where I intend to show that virtualized lessons are not only easier to manage but the performance will be very close to that of real physical machines. And beyond that, the use of other tools, including virtualization solutions and cloud-based solutions."

Environment: Instruction room of the immersive virtual environment.
Script: Upon entering the welcome room, the user finds options granting access to information about the research project and the manual for using the device's controls to access the immersive environment. This information is also available in Brazilian Sign Language (LIBRAS). This environment is individual, meaning it is not shared with other users. In the welcome room, the user can change their avatar. Available avatars are displayed, and the user can select a new avatar using buttons in the environment and the controller's laser. Additionally, users can interact with 3D items in the environment to familiarize themselves with the device's controls. There is an option to enter the virtual learning environment in this environment. By selecting this option, the user is directed to the space where the classroom and laboratory teaching activities will take place.

Interaction Scenario 03: HMD Controls Tutorial Addressing the OSI Model
Actors: Teachers and students of information technology courses with disciplines in computer networks.
Environment: Virtual learning environment.
Script: Upon entering the virtual learning environment, the user will find more information about the project, with the option to access it in LIBRAS. This information guides the user in performing a tutorial activity to become familiar with the headset controls. The activity is related to the OSI Model, where a 3D object represents each layer. By pointing the laser at the 3D object and pressing the controller button, the user will see a description of the respective layer of the OSI Model, which is introductory content to computer networks. Using the grab option on the device controls, the user can hold the 3D objects representing each layer. In this space, there is a 3D object where the objects representing the layers should be placed and stacked. The goal of the activity is to stack the 3D objects in the correct order of the OSI Model layers in the designated space. This interactive activity helps the user familiarize themselves with the headset controls and reinforces learning about the OSI Model layers practically. In this environment, there is the possibility of interaction and communication with other users; however, each user will have their own set of objects to practice with. After completing the activity, the user can explore the virtual learning environment.

Interaction Scenario 04: Auditorium for Didactic Activities
Actors: Teachers and students from information technology courses with disciplines in the area of computer networks.
Environment: Auditorium in the immersive virtual environment.
Script: This virtual environment offers a dedicated lecture area where teachers can present slides, videos, animations, and other didactic materials dynamically and interactively. Students, represented by their avatars, can sit in 3D representations of available seats in this space. In front of the seats, there is a large screen where the teacher displays the educational content. To switch between different educational materials, the teacher can use interactive buttons activated by the laser on the headset controller. This environment creates an engaging learning experience, allowing students to feel

Figure 2. Screens of the environment for user identification.

as if they are in a real classroom while interacting with the content in an immersive way, fulfilling the need for an environment where activities similar to those of a traditional classroom can be developed.

Interaction Scenario 05: IP Addressing Activity Laboratory

Actors: Teachers and students from information technology courses with disciplines in the area of computer networks.

Environment: IP Addressing Laboratory in the immersive virtual environment.

Script: In the Virtual Learning Environment, there is a virtual network laboratory that simulates a natural space with 3D representations of network equipment such as access points, switches, firewalls, racks, and computers. Students can interact with these devices in various ways, including holding them, viewing them, placing them in racks, seeing descriptions, and accessing their settings. In this environment, the user is guided to perform an activity related to the introductory content of IP addressing. A network scenario is presented to the student, who must replicate it by configuring the available devices in the environment. The tool enables the configuration of IP addresses on different devices, with the configuration screen accessed via a button using the controller's laser. An additional screen shows the active devices and their connections, allowing students to visualize the network topology. Through visual interfaces, students can learn and practice IP addressing concepts by configuring IP addresses on network devices and visualizing the connections between the configured devices. Each student has an individual set of equipment to carry out the activity, although collaboration between students is encouraged. Additionally, the teacher can monitor the process, providing guidance and support as needed.

The interaction scenarios were essential for developing the proof of concept of the tool, which covers the IP Addressing curriculum content. Both the platform's architecture and interface were designed to accommodate other virtual environments and facilitate the implementation of a wide range of educational activities related to Computing.

3.3 NetVerse Edu Immersive Environment

The immersive virtual environment proposed in this research, used as a proof of concept, was developed based on interaction scenarios specified from data collected through open coding. **Figure 2** presents the user identification screens according to the requirements of Interaction Scenario 01. The image on the left displays the environment's initial screen, where the user can enter their name. The center image shows the user identification entry screen, while the image on the right presents the option to connect after the identification has been provided.

The entered name will be used to identify the avatar in the learning environment. After entering identification details and selecting the "Connect" option, the user is directed to the Welcome Room, as outlined in Interaction Scenario 02. Users will find usage instructions for the HMD (Head-Mounted Display) controls, project information, and the avatar selection screen in this environment. The user can enable translation into Brazilian Sign Language (LIBRAS) via the accessibility button on the screen. After interacting with the objects in the Welcome Room and selecting an avatar, the user can access the learning environment where the educational activities are conducted. **Figure 3** displays the main screens available in the Welcome Room.

Figure 3. Screens of the Welcome Room

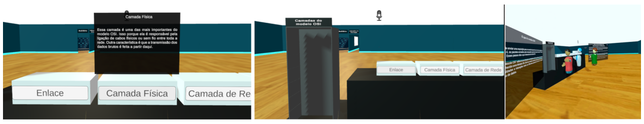

Figure 4. Screens of the OSI Model Activity

In the NetVerse Edu learning environment, the user sees an initial screen displaying research information and guidance for completing the tutorial activity on HMD controls. This information is also available in LIBRAS. Within this environment, users can interact and collaborate. Next to the initial screen, the user can access the HMD controls tutorial activity. This activity aims to familiarize the user with the functions of the controls in the immersive virtual environment. It covers concepts related to Computer Networks, specifically the OSI Model, as described in Interaction Scenario 03. **Figure 4** illustrates the screens for this activity.

In addition to the interactions defined in the interaction scenarios, a thematic room, the Equipment Room, was included. In this space, users interact with network devices and have access to interactive explanations about their functionalities and uses in computer network scenarios. Here, the user can participate in a quiz with questions about Computer Networks. The questions are randomly loaded from an XML file, and new questions can be added.**Figure 5** illustrates the NetVerse Edu Quiz.

According to interaction scenario 04, an auditorium environment was developed for the educational activities, as illustrated in **Figure 6**. After participating in the activities in the auditorium, users can practice the concepts in the IP Addressing Laboratory, created to meet the requirements of interaction scenario 05. In the lab, users encounter a workstation with devices that can be manipulated. The available equip-

Figure 5. NetVerse Edu Quiz

Figure 6. Auditorium.

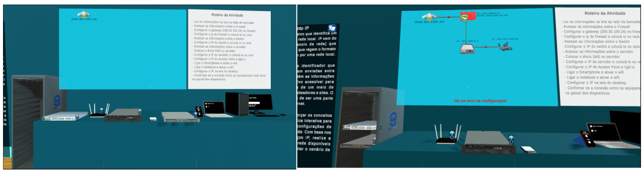

Figure 7. IP Addressing Laboratory

ment includes a switch, access point, network server, and firewall. All devices are configured to simulate real-world conditions of gravity and collision. Each device has buttons that allow access to information and IP configuration settings. Above the workstation is a dashboard displaying the network scenario screen, showing active devices, configured IPs, and connections. **Figure 7** illustrates this environment.

The virtual environment developed in this research aims to present fundamental concepts of Computer Networks practically and interactively, utilizing simulations within an immersive virtual environment. This environment was employed to evaluate the feasibility of the study. One of the current limitations of NetVerse Edu is the partial utilization of its immersive 3D potential. While the platform leverages virtual reality to enhance user presence and interaction, some content remains in a two-dimensional format. This design choice was intentional in the initial development phase. Given the complexity of developing a fully immersive 3D application, priority was given to creating a Minimum Viable Product (MVP) to assess user acceptance and cognitive load before implementing more advanced features.

Future iterations of NetVerse Edu may incorporate advanced 3D features, such as dynamic visualizations of networking concepts. However, implementing these enhancements will require additional development, specialized expertise, and computational resources, which will be addressed in future research phases. A demonstration video of the environment is available at the following link: [https://youtu.be/7Qs9x5CaIr0]

3.4 User Platform Evaluation

This section presents the methods used to evaluate the immersive virtual environment employed as a proof of concept in this research, as well as the data obtained regarding technology acceptance and users' perception of cognitive load.

3.4.1 Technology Acceptance According to the TAM Model

As Al-Adwan *et al*. [2023] described, the TAM was developed to understand the cognitive and psychological factors that influence the acceptance of new technologies. According to this model, the intention to use is a critical factor in adopting and using technologies, influenced by attitudes towards using the technology and the perceived usefulness. Attitudes, in turn, are determined by perceptions of usefulness and ease of use. Furthermore, external variables also influence perceived usefulness and ease of use, allowing for the inclusion of other factors that drive the adoption of a specific technology.

In the context of this research, to validate the proof of concept of the developed immersive virtual environment, the infrastructure of the Augmented and Virtual Reality Laboratory (LARA) at IFPB Campus João Pessoa was used. The laboratory is equipped with six HMD-type virtual reality (VR) headsets, the Oculus Quest 2 model, which provides high immersion and interactivity. These devices feature high-resolution screens positioned directly in front of the user's eyes, promoting an immersive experience and allowing virtual object manipulation through manual controllers or even with the users' hands.

The validation involved nine participants: five students from computing courses at IFPB Campus João Pessoa, three from the Santa Rita campus, and one faculty member from the Technology in Systems for the Internet course. The users explored the immersive virtual environment using VR headsets during the evaluation. They provided feedback on the user experience, physical and logical interactions with virtual equipment, and their overall perceptions of the platform. The activity script included an initial presentation of the research and the developed virtual environment, followed by access to the immersive virtual environment NetVerse Edu. After exploring the interaction scenarios and the functionalities offered by the environment, a questionnaire based on the TAM indicators was applied to measure the level of technology acceptance. The questionnaire was organized into four categories: perceived usefulness, perceived ease of use, intention to use, and suggestions or comments. **Table 10** presents the quantitative responses related to the categories of technology acceptance.

The usefulness was evaluated by considering how useful or relevant users found the tool for educational purposes. The perceived ease of use investigated users' perceptions of how easy it was to interact with the environment and perform the proposed activities. The intention of using the platform was to verify whether participants would consider recommending it to others or using it again. A section was included for users to suggest improvements and provide additional feedback. The questions related to perceived usefulness, perceived ease of use, and intention to use were structured based on the Likert scale, a widely used research method. Each question offered four response options: 'Strongly disagree,' 'Disagree,' 'Agree,' and 'Strongly agree.' **Table 11** compiles the suggestions and comments provided by the participants about the NetVerse Edu platform.

When analyzing the questionnaire responses, it was found that in the category of perceived usefulness, 87% of users fully agreed with the presented questions, indicating a positive perception of the platform's relevance to the educational process. In the category of perceived ease of use, 73% of users also fully agreed, suggesting that the participants con-

Table 10. Responses to the indicators of the TAM questionnaire.

Questions	A	B	C	D
Perceived Usefulness				
Q1 - This immersive virtual environment is useful for learning about computer network equipment.				9
Q2 - This immersive virtual environment helps us understand concepts related to computer networks.				9
Q3 - This immersive virtual environment offers a way to explore practical configuration and troubleshooting scenarios in computer networks.			2	7
Q4 - Using this immersive virtual environment can improve my understanding of the principles and protocols of computer networks.			1	8
Q5 - I interacted with the professor and my peers within the immersive environment.		1	2	6
Perceived Ease of Use				
Q6 - This immersive virtual environment makes it easy to learn about computer networks.			4	5
Q7 - I learned how to navigate and interact with the resources in this immersive virtual environment.			1	8
Q8 - The controls and interface of this immersive virtual environment are easy to understand			4	5
Q9 - I feel comfortable performing tasks related to computer networks within this immersive virtual environment.			1	8
Intent of Use				
Q10 - Would you regularly use this immersive virtual environment as part of your studies on computer networks?		2	3	4
Q11 - I am willing to recommend this immersive virtual environment to other students or professionals in computer networks.			1	8

A) Strongly disagree; B) Disagree; C) Agree; D) Strongly agree

sidered the interface and features of the environment intuitive and easy to navigate. The results showed a greater diversity of opinions in the category of intention to use. About 44% of users intended to use the immersive virtual environment regularly as part of their studies. However, a significantly more significant number, 89%, fully agreed that they would recommend the environment to other professionals and students in the field, reflecting recognition of the educational potential of the tool, even among those who do not plan to use it frequently.

Among the suggestions offered by the participants, most highlighted the need to improve user interaction and task feedback within the virtual environment. In response to these comments, improvements were made, such as adding more collaborative activities, including creating an equipment room and a quiz and more detailed visual and textual feedback related to the tasks performed. These modifications enriched the learning experience by providing greater interactivity and clarity in the educational process.

Table 11. Suggestions and comments from the users regarding the platform.

Users	Suggestion/Comment
1	”Congratulations! I recommend it to anyone looking to enhance their knowledge in the field of networking and related areas.”
2	”The immersive virtual environment was an excellent learning tool, offering both theoretical and practical knowledge on the subject covered. Additionally, it allowed interaction with objects and other users, making it feel like a ’real’ environment. A suggestion would be to include more collaborative activities where all students help each other to complete the proposed tasks.”
3	”Very enjoyable experience! It was possible to learn about the OSI model and IP addressing, revisiting fundamental and relevant concepts for the context. The execution flow to complete the tasks is well-structured, providing a comprehensive understanding of how IP addressing works.”
4	”I was very satisfied with the experience, but I don’t think it’s an activity that should be done frequently.”
5	”In the equipment room information, I believe the text blocks could be replaced with something more interactive, perhaps ’animated flowcharts.’ I think this would make the study practice more engaging.”
6	”Very cool! My suggestion is to make the cooperative aspect (player-to-player interaction) more immersive.”
8	”Very interesting and promising. I believe it only lacked more feedback for task solutions.”
9	”I find it interesting to open the possibility for interaction among students in the case of collaborative tasks or activities. I also highlight the need for user training on the remote control commands. Congratulations on the work!”

3.4.2 NASA TLX Workload Test

The NASA TLX, developed by the National Aeronautics and Space Administration (NASA) [Hart, 1986], is a widely used method to assess multiple dimensions of workload, including mental demand, physical demand, temporal demand, effort, performance, and frustration, as described in **Table 12**. Each of these dimensions is weighted and rated by participants, allowing for a detailed analysis of perceived workload. According to Hertzum [2021], the NASA TLX is recognized for its simplicity and effectiveness. It is widely used in aviation, healthcare, engineering, and systems design to measure the perceived workload during specific task execution.

The application of NASA TLX in this research consisted of asking participants, after completing the activities in the immersive virtual environment, to assess their perceived workload in each of the six dimensions on a scale from 0 to 100. The tool was used in its raw version, where the final score is the average of the intensity ratings for each dimension without assigning weights. This choice of the raw ver-

Table 12. Description of the NASA TLX dimensions.

Title	Endpoints	Descriptions
Mental Demand	Low/High	How Much mental and perceptual activity was required (e.g thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/High	How Much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/High	How Much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or youself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/High	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

sion simplified the data collection process and allowed for a direct analysis of the participants' experiences. In the case of the immersive virtual environment NetVerse Edu, this approach was sufficient to evaluate the workload perceptions associated with using the platform, providing data on how participants experienced the proposed tasks regarding cognitive and physical effort, time management, and frustration levels. The interpretation of the reference values was based on the proposal by Prabaswari *et al*. [2019], as shown in **Table 13**.

The study involved nine users who interacted with the immersive environment and completed the proposed educational activities. After finishing the activities, the participants answered the NASA TLX questionnaire, assigning scores to the six workload dimensions based on their subjective perception of the intensity of each aspect. **Table 14** presents the scores assigned by each participant for each of the evaluated dimensions and the overall averages calculated for these dimensions. The data analysis allowed the identification of which areas of the immersive environment may have imposed a higher or lower workload, providing valuable insights to enhance the design and usability of NetVerse Edu.

Table 13. NASA TLX interpretation scoring.

Workload	Value
Low	0-9
Medium	10-29
Somewhat high	30-49
High	50-79
Very high	80-100

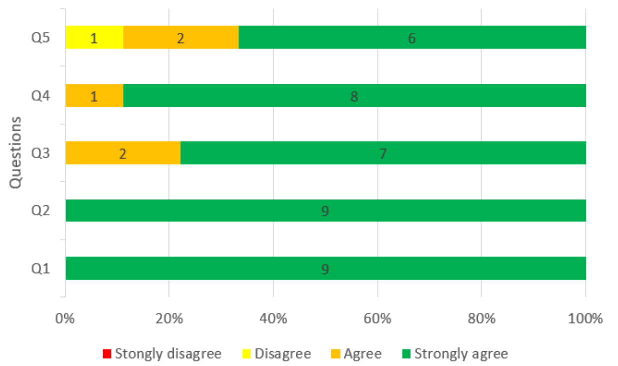

Figure 8. Perceived Usefulness.

4 Results and Discusions

The analysis of the TAM results revealed an overwhelmingly positive perception of the Perceived Usefulness of the immersive virtual environment NetVerse Edu, designed for teaching computer networks. All participants considered the helpful environment for learning, particularly in familiarizing themselves with equipment and understanding the course concepts. Questions Q1 and Q2 showed complete user agreement, indicating that the environment meets its educational goals. However, some areas for improvement were identified. While most participants recognized the usefulness of the environment for practical simulations of configuration and troubleshooting (Q3), two users agreed but did not fully agree, suggesting that the environment could offer more immersive and realistic experiences to reinforce the practice of theoretical knowledge. Additionally, interaction in the environment (Q5) showed divergences, with one participant disagreeing with the effectiveness of this functionality. Although it enabled collaborative activities, the environment was used individually, which may have limited interaction. **Figure 8** summarizes the TAM results related to Perceived Usefulness.

The results regarding Perceived Ease of Use indicate an overwhelmingly positive evaluation by the users. In question Q6, which assessed the general ease of use for learning computer networks, 5 out of 9 participants fully agreed. In contrast, four agreed, suggesting a general perception of ease but with possibilities for improvement. In questions Q7 and Q9, which addressed navigation and comfort in tasks, 8 out of 9 participants fully agreed, indicating that most did not encounter significant difficulties using the environment. Only one participant provided a less favorable response, possibly due to a need for more familiarity with the tools or the learning curve associated with the device. Question Q8, which referred to understanding the controls and interface, had results similar to Q6, with five responses of 'Totally Agree'

Table 14. Results of the Perceived Workload Evaluation.

User	Mental Demand	Physical Demand	Temporal Demand	Effort	Performance	Frustration	Average
01	90	90	90	70	20	0	60
02	60	50	50	50	20	10	40
03	80	40	50	80	10	30	48.33
04	70	70	20	70	0	0	38.33
05	30	30	40	50	0	0	25
06	60	30	0	30	0	0	20
07	40	70	0	60	30	20	36.67
08	80	50	70	90	20	20	55
09	80	20	50	40	100	0	48.33
Average	65.56	50	41.11	60	22.22	8.89	41.30

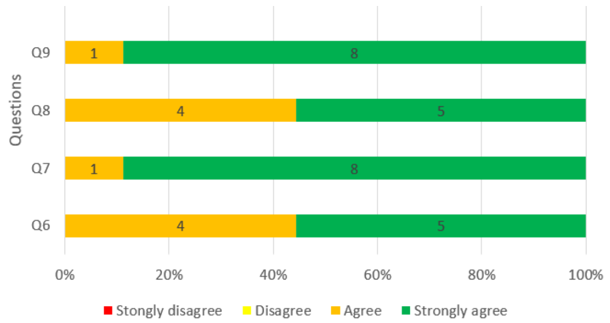

Figure 9. Perceived Ease of Use.

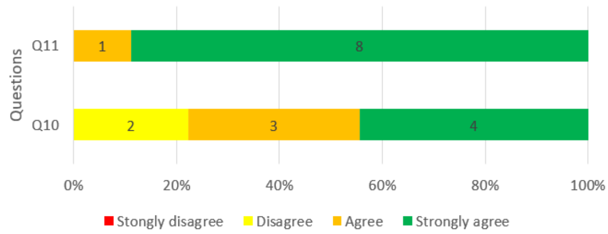

Figure 10. Intention to Use

and 4 of 'Agree.' While most considered the controls intuitive, some still perceive areas for improvement. The data indicated a positive acceptance of ease of use, with room for adjustments to enhance accessibility and comfort. **Figure 9** illustrates the results regarding Perceived Ease of Use.

The analysis of the results regarding Intention to Use revealed divided perceptions among the participants. In question Q10, which assessed the willingness to use the environment regularly, four users fully agreed, three agreed, and two disagreed, indicating that while most see value in continuous use, some need to be sufficiently motivated. This hesitation may be related to limitations in content, user experience, or personal preferences for other learning approaches. Some participants also reported fatigue, requesting breaks during the tests. In question Q11, regarding the willingness to recommend the environment to others, the results were more consistent: 8 participants fully agreed, and one agreed, suggesting that most considered the environment valuable and practical to recommend to others. In summary, as predicted by the TAM model, these results reflect a positive perception regarding Utility and Ease of Use. **Figure 10** illustrates the results of Intention to Use.

The evaluation process was necessary for identifying the strengths and the areas that needed improvement in the virtual environments. The improvements suggested by the participants were incorporated to optimize the environments for more efficient use in distance learning of computer networks. After receiving feedback, adjustments were made, prioritizing enhancing the virtual environments' usability, interactivity, and pedagogical effectiveness to offer students a more engaging and practical learning experience. After analyzing the results regarding the acceptance of the immersive virtual environment based on the TAM model, another dimension of the user experience was explored: the perceived workload while using the tool. While the TAM focused on usability and intention to use, the NASA TLX complemented this evaluation by investigating the perception of workload, providing a more comprehensive analysis of the experience in the immersive environment.

The analysis of mental demand, based on the results from the NASA TLX test, revealed that users found the activities in the virtual environment cognitively challenging. The average of 65.56 classifies this demand as "High," indicating that the tasks required considerable attention, reasoning, and information processing. The variation in responses, with scores ranging from 30 to 90, suggests that some users experienced a high mental workload while others had a more balanced experience. Factors such as the complexity of interactions, the volume of information processed, and familiarity with the environment and devices may have influenced these perceptions. **Figure 11** presents the results of the NASA TLX application regarding Mental Demand.

The physical demand analysis revealed that users perceived a slightly elevated physical effort when interacting with the immersive virtual environment. With an average of 50, the physical demand was classified as 'High,' indicating that the tasks required significant movement and bodily actions. This result may be related to repetitive gestures, manual interactions, or controllers demanding prolonged physical effort. The high physical demand could be associated with the interface and input devices. For example, the immersive virtual environment developed and tested in this research requires continuous movements of the body, arms, and hands, which can increase the perception of physical effort. **Figure 12** presents the results related to Physical Demand.

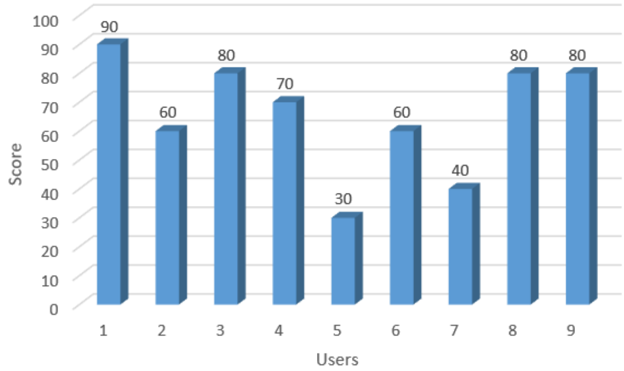

Figure 11. Mental Demand

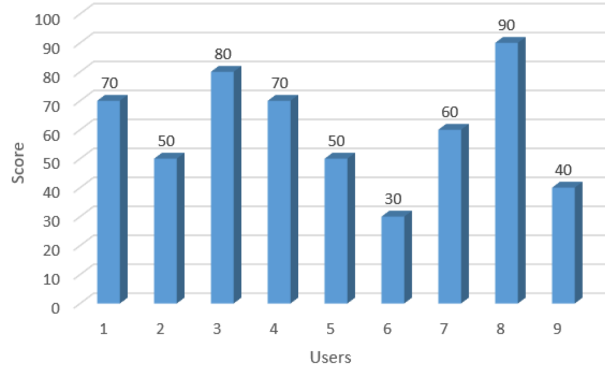

Figure 14. Effort

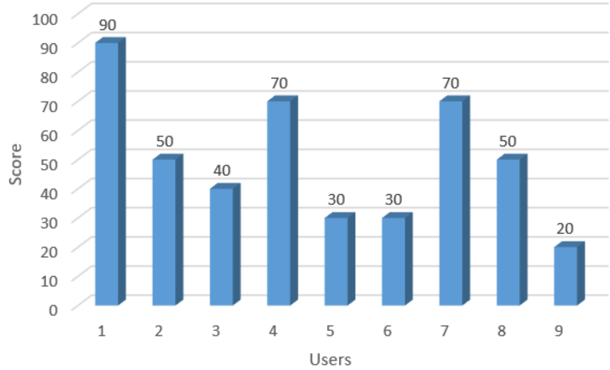

Figure 12. Physical Demand

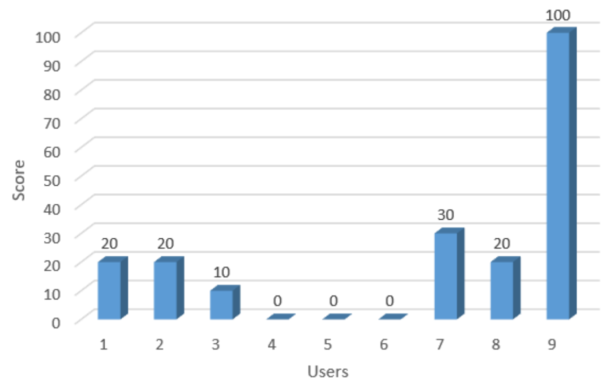

Figure 15. Performance

The analysis of Temporal Demand revealed that users perceived a moderate time load when interacting with the immersive virtual environment, with an average of 41.1. This indicates that most participants faced some time management demands but without a sense of extreme urgency. The scores varied from 0 to 90, and this variation in perception may be related to users' familiarity with the topics covered and the HMD device, as well as the complexity of the proposed activities. **Figure 13** presents the results related to Temporal Demand.

The analysis of the effort dimension revealed that users perceived a high level of effort required to perform activities in the immersive virtual environment. With an average of 60.00, the effort was classified as "High," indicating that participants needed to dedicate themselves intensively to complete the tasks. The responses ranged from 30 to 90, reflecting the technical complexity of the content and interactions required by the environment. The high demand for effort may be related to the combination of cognitive and physical challenges imposed by the immersive virtual environment, especially in tasks that require simultaneous reasoning, concentration, and physical interaction. **Figure 14** presents the results related to the effort perceived by users.

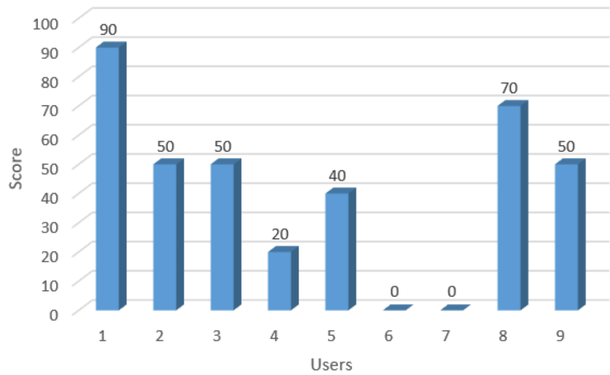

Figure 13. Temporal Demand

The analysis of the performance dimension revealed that users expressed moderate satisfaction with their ability to complete tasks in the immersive virtual environment. With an average score of 22.22, the performance was classified as 'Medium.' However, a possible inconsistency was observed in one user's score, who attributed an extremely high rating (100) to performance. Given that the NASA TLX performance scale is inverted — with higher scores indicating a perception of lower success — and this information was clearly communicated to participants before and during the questionnaire, it is possible that this user misinterpreted the scale. Even disregarding this user's assessment, the performance dimension would remain classified as 'Medium,' with a recalculated value of 12.5. **Figure 15** presents the results related to the performance perceived by users.

The analysis of the frustration dimension in NASA TLX revealed that most users experienced low frustration levels when interacting with the immersive virtual environment. With an average score of 8.89, this dimension was classified as 'Low,' indicating that most participants did not encounter significant obstacles or discomfort during the activities. The scores ranged from 0 to 30, with many users reporting val-

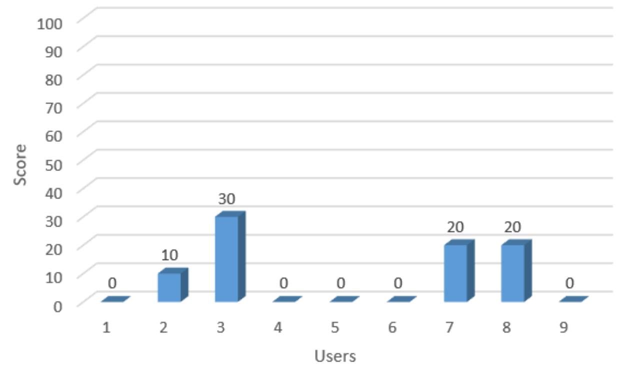

Figure 16. Frustration

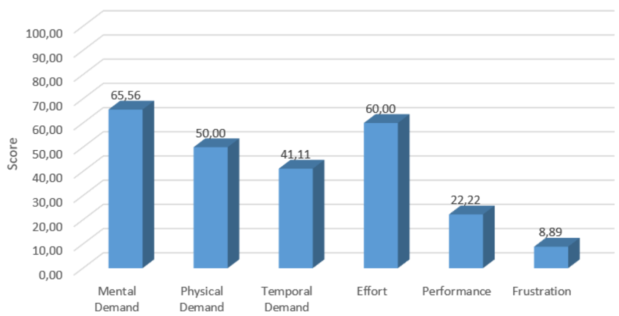

Figure 17. Averages of the NASA TLX Dimensions.

ues close to zero, suggesting a relatively smooth experience with no significant setbacks. **Figure 16** presents the results obtained regarding users' perceived frustration.

The analysis of the NASA TLX results revealed significant variations in users' perceptions of different workload dimensions when interacting with the immersive virtual environment for teaching computer networks. The mental demand and effort dimensions presented the highest indices, classified as 'high' workload, indicating that the tasks were perceived as cognitively challenging and required considerable effort from the participants. **Figure 17** compares the results obtained for each NASA TLX dimension.

5 Conclusion

Technology and education have an intrinsic and long-standing relationship, with technological contributions expanding at the pace of technological advancements. Technological tools can effectively support the teaching-learning process, which also applies to Augmented, Virtual, and Mixed Reality technologies. However, immersive technologies in education still need help, such as digital exclusion, high costs, the production of educational content, and a lack of adequate infrastructure. Academic research plays a vital role in seeking ways to integrate these technologies into the educational environment and overcoming such obstacles.

In this context, this research aimed to evaluate the feasibility of an immersive virtual environment for teaching computer networks and measure the level of acceptance by students of computer science courses and the perceived workload during use. This research is noteworthy for its pioneering nature at the Federal Institute of Paraíba in applying this technology to computer science education.

The research began with a systematic literature review to identify available platforms, technological resources employed, and the limitations of using immersive environments in education. The results showed that most available platforms are proprietary and exhibit some instability in maintenance, which could compromise the continuous development of educational environments. The highlighted difficulties included limited access to technology, the development of immersive environments, and physical discomfort, such as nausea caused by the devices. Additionally, the review revealed a lack of studies on using these environments by people with disabilities. These results influenced the direction of the research.

In response to the first research question, the NetVerse Edu immersive virtual environment proved a viable solution for supporting distance learning in Computer Networks. Open-source tools strongly supported this viability, eliminating reliance on proprietary platforms for educational purposes. As a result, it was possible to create a flexible and expandable immersive environment. The developed environment can be expanded to other areas of computing, fostering a multidisciplinary virtual learning space. The expertise gained through the research and the infrastructure available at LARA, IFPB João Pessoa Campus supports the project's continuation.

Regarding the acceptance of the technology, the results indicated that students' perceptions of the utility of the immersive virtual environment for teaching computer networks were positive. Participants recognized the value of NetVerse Edu as a valuable tool for learning, highlighting its effectiveness in familiarizing with equipment and understanding technical concepts. The responses indicated that the environment meets pedagogical objectives, providing a beneficial and enriching experience for learning computer networks. Regarding ease of use, the results showed that most users consider the environment intuitive and accessible. The high evaluation of navigation ease and control comprehension suggests that the environment's design is efficient and facilitates user interaction.

Although the acceptance of the virtual environment was positive, reflected in users' high willingness to recommend it to others, the intention for regular use showed more division. Some participants hesitated to integrate the environment as a constant part of their studies. This suggests that, despite recognizing the utility and ease of use of the NetVerse Edu platform, there are still barriers to the continued adoption of this technology as an educational tool.

Finally, regarding the perception of workload, the study revealed that students perceived a considerable workload, especially regarding mental demand and effort. The mental demand was classified as 'High,' reflecting the significant cognitive requirement of the tasks in the environment, which may be associated with the complexity of the activities and the need for concentration to deal with the concepts covered and the use of the device. Physical and temporal workload also had a moderate impact on students' perceptions. The physical demand was classified as 'Moderate,' indicating that the physical interactions in the immersive environment required moderate user effort. Temporal demand was also classified as 'Moderate,' suggesting that, although students felt some time pressure, this dimension was manageable for most participants.

These combined dimensions show that the immersive virtual environment generated a balanced workload between physical and temporal demands, with greater emphasis on mental workload.

The perceived effort was classified as 'High,' reflecting the need for significant dedication to complete the proposed tasks. This high level of effort, combined with the high mental demand, suggests that students need to engage to navigate and interact with the environment effectively and actively. Despite these demands, the reported frustration levels were low, indicating that students did not feel excessively frustrated or incapable of performing the activities even with a high workload. The physical demand was classified as 'Moderate,' indicating that the physical interactions in the immersive environment required moderate user effort.

As future work, the immersive virtual environment is expected to be adapted for other platforms, such as smartphones and computers, to enhance accessibility and reach a broader audience, considering the challenge of access to VR devices. This adaptation will facilitate comparative studies across platforms, examining variations in usability and user acceptance between mobile and desktop versions. Additionally, it will assess whether the pedagogical impact of the environment remains consistent regardless of the technology used.

Declarations

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Authors' Contributions

Erberson Evangelista Vieira contributed to the original draft of the Investigation, Conceptualization, Methodology, and Writing. Francisco Petrônio Alencar de Medeiros contributed to the Conceptualization, Methodology, Supervision, Writing – Review, and editing.

Competing interests

The authors declare that they have no financial, professional, or personal relationships that could be construed as influencing the content or conclusions of this research. No conflicts of interest, whether direct or indirect, exist in relation to this study.

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