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RESEARCH ARTICLE

Analysis of the Mental Workload Associated With the Use of Virtual Reality Technology as Support in the Higher Educational Model

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ABSTRACT In recent years, the continuous development of digital technologies has expanded the possibilities for their application in the educational environment, allowing to improve the learning experience by making it more interactive, visually appealing, and accessible to different learning styles. The use of technologies, such as augmented reality (AR) and virtual reality (VR), is transforming the educational model, offering more immersive, personalized, and effective educational experiences for students. Nevertheless, it is essential to consider the mental workload that students may experience when using immersive technologies. This load can manifest itself as difficulty in understanding concepts, frustration, cognitive effort, time demands, among others. Therefore, mental workload of immersive educational experiences must be addressed, as it can negatively affect the learning experience for students. If students experience feelings of overwhelm or frustration, they are less likely to retain information and improve their learning. There is currently research on how to design user interfaces in VR applications to reduce mental workload. This includes the use of user-centered design techniques and the implementation of more intuitive interaction strategies. Nevertheless, the research presented in this paper is not only focused on the appropriate development of a VR application to support the educational model, but also on the analysis of the mental load perceived by students. For this purpose, the NASA-Task Load Index (TLX) tool was used in a group of volunteer students from a university in Ecuador. The main findings are encouraging and show that the mental load experienced by students is relatively low. However, to mitigate the mental workload associated with the use of immersive technologies, it is important to design educational experiences to be intuitive, easy to use and not overload the student with unnecessary information. Furthermore, it is essential to incorporate rest periods and restrict continuous use to avoid mental fatigue.

INDEX TERMS Active learning, authentic learning, fun learning, VR application, VR in learning, mental workload, NASA-TLX.

I. INTRODUCTION

The contemporary world, which is increasingly dependent on technology, is witnessing a significant transformation in the manner in which numerous activities of daily life are

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conducted [1]. The advent of the metaverse, which can be defined as a fully immersive digital environment, is presented as an innovation in the field of technologies. This new digital era provides students with realistic experiences through avatars, driven by technologies such as augmented reality (AR), virtual reality (VR), extended reality (XR), mixed reality (MR), artificial intelligence (AI), among others. In this context, a number of potential applications have been identified, including remote work, remote medical care, and innovation in the educational model [2], [3].

Therefore, the introduction of digital technologies in education has become essential to meet the demands of new teaching and learning methods [4]. Among these technologies, VR has gained attention and recognition for its potential to revolutionize and innovate the educational system [5].

VR can be defined as a form of human-computer interaction technology that recreates real-world environments [6]. This technology simulates the senses, including touch, vision, and hearing, within a simulated environment, thereby creating a realistic impression of the scene in question [7].

This technology has been used in a variety of fields, ranging from entertainment [8], [9], video games [10], and education [11], [12], [13], among others. VR systems offer a more effective and efficient learning approach, making use of a smaller budget compared to traditional teaching methods in specialized laboratories [14], [15]. In addition, they facilitate multiple practices, especially in situations where the required environments are dangerous or unusual [16], [17], [18]. Students can explore educational environments, build prototypes, or perform simulations without any restrictions [19]. These tasks can enhance students' experience of simulated hands-on learning [20]. VR technology is expected to enable visualization of abstract concepts that are difficult to grasp, improve conceptual understanding, and provide immersive and interactive environments to enhance and motivate learning [21], [22], [23], [24].

The integration of VR technology as a support in the educational model has the potential to transform traditional learning dynamics by providing a more immersive and participatory experience for students [25]. This interaction can be pivotal in overcoming the passive teacher-student and student-student attitudes that often arise in conventional educational settings [26]. Moreover, the opportunity to experience authentic, immersive sensations in a learning environment that employs VR technology offers a promising avenue for enhancing the educational process [11], [27].

In recent years, different solutions based on digital technologies have been developed to help students better understand abstract concepts, such as programming languages and computational thinking [28], [29]. However, there is very little research that has analyzed the mental workload that these solutions can manifest in students, such as frustration, cognitive effort, time demand, among others. It is important to address this issue as this can negatively affect the learning experience in students [30]. If students feel overwhelmed or frustrated, they are less likely to retain information and improve their learning [31].

With VR, learning can be transformed into a fun experience if appropriate teaching and learning methodologies are used [22]. Teaching programming languages is particularly challenging due to the abstract nature of many of their concepts. Students often struggle with visualizing computational logic and syntax, which can lead to high dropout rates and demotivation. VR offers a unique opportunity to overcome these challenges by providing an immersive and visual learning environment that can make abstract concepts more accessible and understandable [32]. Although VR has been used in a variety of fields, there is very little research that has systematically assessed the mental workload that these solutions can impose on students, such as frustration, cognitive effort, time demand, among others. This gap in the literature is critical because excessive mental workload can negatively affect the learning experience and educational outcomes [31], [33]. This research aims to fill this gap by evaluating the user's mental workload in the context of teaching programming through VR. That is why in this research we assessed the mental workload perceived by students when using an immersive VR application (FreeDev) for basic programming learning. This application was developed specifically to motivate students in obtaining skills needed to understand computational logic and programming languages.

The objectives of this research were:

- Objective1: To identify whether the use of the FreeDev application allowed students to improve their understanding of basic programming.
- Objective 2: To analyze whether students experience any level of frustration, effort, and temporal, mental, and physical demands when using a VR application to support education.
- Objective 3: To identify effects on the use of VR applications and propose recommendations.

Furthermore, based on the analysis of the results, ways to mitigate the mental workload and fatigue associated with the use of immersive technologies will be identified. This research intends to find uncovered spaces to generate opportunities for new lines of research in educational innovation using VR technology. Additionally, by identifying the sources of mental workload and frustration, this research can inform the design of future VR-based educational applications that are more effective and less cognitively demanding. This will not only improve the learning experience for students but also increase knowledge retention and motivation to learn.

This section presents an overview of the applications of VR in various fields, with a particular focus on its use in education. Section II presents a review of the existing literature on the subject. Section III outlines the methodology employed to attain the proposed objectives. Section IV presents the findings of the study. Section V comprises a discussion of the results. Section VI presents the conclusions, and Section VII outlines potential avenues for future research.

II. PREVIOUS WORK

A. VIRTUAL REALITY IN EDUCATION

With the rapid development of science and technology, educational methodologies have been innovating and diversifying progressively [34]. During the last few years, several innovative approaches to teaching and learning are presenting educational materials in a highly engaging way [35]. There is a study showing brain activity around basic emotions such as happiness and surprise, proposed by Professor Paul Ekman, when a user is exposed to two-dimensional (2D) content compared to VR or three-dimensional (3D) modalities (3D) [3], [36]. Overall, there are significant differences in the induction of the same discrete emotions in VR-3D and 2D modalities, with greater brain activation in VR-3D modalities. Thus, an immersive environment offers several advantages over traditional learning methods, which in turn improves spatial understanding of concepts that may become abstract [7], [35], [37].

VR has become a popular medium for application in a few educational areas [38], [39]. An example of this is the analysis of the impact of different technological approaches to VR on the teaching and learning of English as a foreign language (EFL) [40]. In contrast, the implications of immersive extended realities have been studied, as educational tools for existing pedagogy and being able to use them for teaching and learning engineering mathematics in higher education [38], [40], [41]. From the education perspective, VR technology has been used for teaching second languages [42], programming [22], [28], biology [43], anatomy [44], gynecology [17], forensic scenarios [45], and in engineering education [46], [47]. Moreover, this technology is used to plan and practice complex surgical procedures, with the goal of improving accuracy prior to actual surgery [48], [49].

VR technology has been used, along with the internet of things (IoT), the cloud computing, and mobile learning, in teaching physical education to students in colleges and universities [39], [50]. As well as the training of different sports disciplines among which basketball stands out [51], [52].

B. RELATED WORK

Because this technology is used to enhance spatial understanding of concepts that may become abstract [37], the adoption of VR technology finds its natural path into immersive educational environments for teaching programming [22]. Learning and acquiring expertise in computer programming necessarily involves the development of computational thinking and problem-solving skills [7], [23], [53].

Based on this, Chandramouli, et. al. [22] proposes the design of a VR framework for "fun-based" interactive programming instruction in engineering education courses. The goal of this research tries to make students realize the "power of programming".

Tanielu, et. al. [54] suggest an experience with VR for the reduction of abstraction of concepts about object-oriented programming, this with the objective that students can improve their understanding about objects and classes.

Also, Sujani, et. al. [32] offer a data visualization and storytelling system using VR. This system aims to provide programming languages to students, who will be engaged and have interest in working on programming by themselves while visualizing their output immediately.

Singh, et. al. [27] have students, using a VR experience, learn through visualization of programming code. The program allows them to highlight part of the code to observe how that part of the code is represented in virtual space.

Barbosa, A. et.al. [55] propose the creation of an AR-based tool that allows students to learn basic programming concepts. Algorithms are formed by block assembly, thus solving one of the main problems that most students have, syntax errors.

Wee, et. al. [28] suggest a VR-based framework with three modules for teaching about, abstract programming concepts, simulation techniques, collaborative learning. They used an experimental and a control group to conduct the experimentation and concluded that students prefer to learn by visualizing abstract concepts in VR. In addition, the results also show that participants agree that the experience was a good complement to conventional lessons.

This research is based on previous work integrating unique aspects such as:

- Integral Skill Development: Unlike previous studies that focus on specific aspects such as engagement or the reduction of syntax errors, this VR application aims at the integral development of computational thinking and problem-solving skills, which are crucial for mastering programming.
- Empirical Evaluation: A pre-test and post-test design was used to measure the impact of FreeDev on students' programming proficiency. This includes not only cognitive improvements but also psychomotor domain enhancements.
- Mental Workload Analysis: The NASA TLX tool was incorporated to evaluate mental workload, providing a nuanced understanding of how VR affects the cognitive load of students. This addresses a gap in the existing literature, where the cognitive demands of VR-based learning tools are often overlooked.

III. METHODOLOGY

A. MOBILE APPLICATION DESIGN

For this work we used a mobile application called FreeDev, which was made with the help of Unity 2021.3.12f1 LTS software, in conjunction with Visual Studio 2022 Community Edition. These tools have been widely used for the design and construction of video games using VR technology. The characteristics of these platforms are explained in Table 1.

For the development of the application, the Oculus Meta Quest 2 SDK was used, in addition to the following libraries:

- UnityEngine / UnityEngine.UI: for the connection and use of the internal functions of the Unity engine.

TABLE 1. Development platforms used.

Development platforms	Features
Unity	Unity is a video game development platform that has different versions of long-term support (LTS). Also, it can be defined as a game engine that provides a complete environment for the development of 2D and 3D video games, as well as MR. The developed games can be exported for use in different devices such as, desktop computer, laptop, console, smartphone, tablet, Oculus, among others.
Visual Studio 2022	Visual Studio is an integrated development environment (IDE) developed by Microsoft. This software is used to write, debug, and compile programming code. It includes a package that can be installed to connect to Unity and debug code while running the application.

TABLE 2. Requirements for the design of mobile applications [62].

Requirements	Characteristics
Simple and easy to use	Provide ease in the game, the user should not get caught in the links of the different sections
Consistent interfaces	Use known functionalities that resemble computer menus
Nice design	Generate satisfaction, enthusiasm, and fun by using the different controls in the activities carried out by the application
Feedback	Provide an understanding of mistakes made to improve task interpretation
Multimedia content	Generate use intent by creating multimedia interfaces that attract the user's attention
Intuition	Avoid user disorientation due to total number of interactions
Motivation	Motivate the user with kind messages while progressing through the game

- UnityEngine.XR: for XR-specific functionalities, which include VR.
- Oculus.Interaction: for the connection and interaction of the user with the Oculus Meta Quest 2.

In the development of an application designed to facilitate educational processes, it is of paramount importance to establish the requirements and needs to be addressed with clarity and precision [56], [57]. These elements will guide the creative process, ensuring that the application will be effective in meeting its educational objectives [56]. Likewise, the design must ensure that the application motivates students and encourages them to use it [58], [59]. Therefore, the application should have a user-friendly interface, be simple, coherent, and intuitive, avoiding redundancy and offering interactive navigation [56], [57], [60], [61]. In this case, the requirements were identified in a previous study [62] and are listed in Table 2.

Besides, from the requirements defined in our previous work [62], the following main functionalities that this application must have specifically been identified:

- Interaction with the blocks: The application must allow the student to interact with the code blocks and the interface in a free and intuitive way.
- User-friendly environment: The application must allow the user to interact in an environment in which it is possible to perform the proposed exercises.
- Error control: The application must have the ability to correct the user in the presence of errors in the constructed algorithm.
- Code export: The application must be able to export the algorithm created by the user to different programming languages, the most basic ones being C, C# and Python.

Each development cycle involved the selection of requirements and the scheduling of activities for the FreeDev application [63]. Subsequently, these activities were carried out within a set time frame, defined in Table 3. If problems arose, the team met briefly to resolve doubts and continue with the project. The priority of each cycle was determined by the final project objectives, and all stages received a priority rating of no less than nine. At the end of each cycle, the work was reviewed, demonstrated, and adapted in a meeting with the entire team to finalize the development of FreeDev.

Finally, the developed application has four levels, which are placed from the lowest level of difficulty to the most complicated. This to challenge the students to motivate them and foster a sense of discovery.

Figure 1 illustrates the way in which the exercises to be solved are presented. Each one of them contains all the necessary information, together with the blocks, to be able to build the necessary algorithm. This image displays information written in Spanish because the mobile application was designed in this language (“Exercise: Read the variable “X” and determine if it is greater or less than 7,

TABLE 3. Iterations required for the construction of the VR application.

Iteration Number	Definition	Priority	Iteration duration (weeks)
1	Creation of blocks with instructions	9	1
2	Creating interaction	9	2
3	Creating block customization	9	2
4	Creating environment	9	1
5	Creating UI elements	9	2
6	Creating exercise verification	9	2
7	Creating syntax check	9	3
8	Creating export logic	9	2
9	Create different levels (4)	9	2
10	Create welcome and completion screen	9	1
Total duration of mobile application development		18 weeks	

FIGURE 1. Mathematical computation exercise using FreeDev application.

without considering the case that it is equal. If it is greater, add 1, if it is less, subtract 1.'').

Unlike other similar initiatives in the current literature, this research did not focus solely on the design aspects of the VR application, but on the assessment of the mental workload perceived by students. For this purpose, the NASA-Task Load Index (TLX) tool was used [64], [65].

B. PARTICIPANTS

A total of 80 students from a higher education institution in Ecuador took part in this research project. The participants were selected using convenience sampling, due to accessibility and availability to participate, without any compensation, in the study. Of the 80 participants, only 60 completed the survey. Of these, 55 were male (92%) and 5 were female (8%). The students' ages ranged from 18 to 19 years old.

Although the sample size is relatively modest, it is important to note that this study focused on evaluating the mental workload perceived by students, when using a VR application for teaching programming. Participants were specifically selected based on their interest and experience in this field. Furthermore, although the sample comes primarily from a single university, it is worth noting that this institution has a very diverse and representative student population in terms of academic background and programming knowledge levels.

C. EXPERIMENTAL PROTOCOL

Each participant accepted an informed consent given prior to their participation, which was voluntary and without any influence from the researchers. The experiment began with an induction on the use of the FreeDev application. Each participant was able to ask questions and make comments on the designed application.

D. TASKS

Participants were required to complete the following tasks:

- Pre-test: Questionnaire that students had to complete before the start of the application, which contained questions to evaluate basic programming concepts.
- Use of FreeDev: This task lasted approximately 25 minutes per student.
- Post-test: After finishing the use of FreeDev, students were asked to fill out the pre-test again.
- Workload: Each participant, on a voluntary basis, was asked to answer a questionnaire provided to assess the perceived mental workload of using the VR application.

The information provided in this research allowed identifying the mental workload of the VR application designed to support programming education. This information may be useful for teachers and educational institutions that want to include VR to innovate traditional methodologies and thus adequately respond to current learning challenges.

E. WORKLOAD ANALYSIS

The NASA-TLX tool is a popular technique for measuring mental workload, which analyzes mental demand, physical

TABLE 4. NASA-TLX rating dimension description [65].

Title	Description	Scale
Mental Demand (MD)	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?	1-20
Physical Demand (PD)	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?	1-20
Temporal Demand (TD)	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?	1-20
Performance (PE)	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?	1-20
Effort (EF)	How hard did you have to work (mentally) to accomplish your level of performance?	1-20
Frustration Level (FL)	How insecure, discouraged, irritated, stressed, and annoyed or secure, gratified, content, relaxed, and complacent did you feel during the task?	1-20

demand, time demand, performance, effort, and frustration level, on a scale from 1 to 20, where 1 is the lowest value and 20 is the highest value [64], [65]. The six dimensions, together with the questions associated with each, are set out in Table 4. These are used to derive an overall average workload score associated with the use of the VR application. A comparison was also made between each of the six dimensions to identify which aspect of the compared pairs contributes most to the workload of the task performed.

Based on the responses to the pre-test, and the results of the mental workload analysis, we attempted to test the following hypotheses:

H1: There is an improvement in understanding and retention of programming concepts before and after using the FreeDev application.

H2: The level of mental workload, perceived by students when using the application, is low.

The pre-test and post-test methodology in the group was used due to the low number of students willing to participate in this research.

IV. RESULTS

This section presents the results of the analysis conducted on the use of a VR educational application for learning programming. In particular, the use of this application is explored using a pre-test and post-test methodology to identify whether immersion in virtual environments can improve the understanding of fundamental programming concepts, as well as promote more active and hands-on learning. In contrast, the results obtained from the NASA-TLX survey are detailed along with the specific dimensions of mental workload experienced by students.

A. PRE-TEST

As part of the activities in this research, participants were asked to solve a test, prior to using the mobile application, on basic programming knowledge. After using FreeDev, they were again asked to complete the same test and the results obtained were compared. In the test prior to using the application, the average score was 6 out of a maximum of 10 points. However, in the second test, after the use of the mobile application, the results showed an average score of 7.9. This result indicates that the use of FreeDev helped students to obtain a higher average score of 1.9 points, which translates into a 19% improvement in the overall average. This result confirms the first hypothesis H1 and shows that there is a positive variation in programming concepts after the use of the application using VR.

B. MENTAL WORKLOAD ANALYSIS

To assess mental workload, the test provided by the NASA-TLX tool was used. The 60 participants responded to the survey based on the six workload dimensions distinguished by NASA-TLX: mental demand (MD), physical demand (PD), temporal demand (TD), performance (PE), effort (EF) and frustration level (FL). It can be observed, in Table 5 and Figure 2, that the PE dimension had the highest rating. This means that students perceive that they can perform better when using the mobile application. From here, the responses are in the lowest 50% of the dimension associated with the NASA-TLX survey.

The second place is occupied by the MD dimension, which shows that using FreeDev resulted in an initially demanding task. The third place is occupied by the TD dimension, which means that the time pressure that was perceived by the student to complete the application tasks was low. In fourth place is the EF effort dimension, which indicates that students perceived a low level of mental effort when using FreeDev. In fifth place is the FL dimension, which shows that students perceived little frustration in using the application. Finally, it is evident that students did not perceive any physical demand (PD) to complete the activities requested in FreeDev.

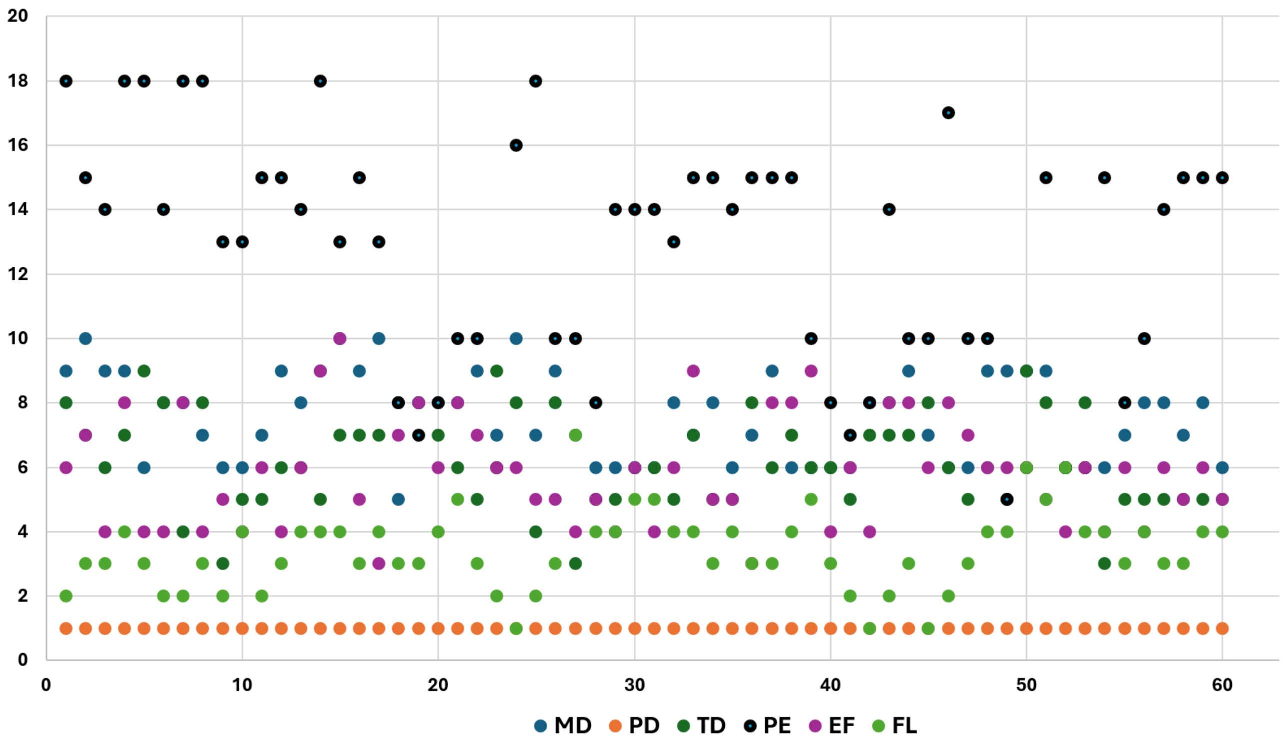

FIGURE 2. Answers to the six dimensions of NASA-TLX.

TABLE 5. IBM-CSUQ results (1 – 20).

Students	MD	PD	TD	PE	EF	FL
60	7.55	1.00	6.18	12.52	5.85	3.40

Table 6 shows the six dimensions that are assessed in the NASA-TLX tool grouped in pairs. The students were asked the following question: example of the first column, "After completing the designated tasks, choose among the pairs which generated the most frustration when using the application. Each cell indicates how many times a dimension was perceived as more significant compared to another in each pair. The table analysis shows that MD is the most significant dimension perceived by the students, followed by PE and EF, PD is the least significant, suggesting that students perceive almost no physical load when using the FreeDev application. These results indicate that FreeDev is cognitively demanding but not overwhelming, and students feel they can perform well without experiencing high frustration. Tables 7 and 8 show the data on the students' perception when using FreeDev. With these data we proceeded to calculate the mental workload using the NASA-TLX tool. Table 7 displays an example of quantitative calculation of the perceived mental workload in participant number one. In column A is placed the MD weight, i.e., how many times MD is repeated in Table 6, compared to its peers. Column B is the score obtained in MD in Table 5. Column C and D respond to a simple formula between columns, B x 5 and C x A. The total quantitative score, which defines the perception of student one regarding the mental load in the use of the mobile application, was 665 points. This value, according to Table 7, indicates that student one perceives an average mental load when using the mobile application.

Table 8 demonstrates the total result of the level of mental workload perceived by the students who participated in this research. There are 28 students (46.67%) who perceive a low level of mental workload when using the application.

In contrast, the remaining 32 students (53.33%) perceive a medium level of mental workload when using the application. It is important to note that there is no student who perceives a high level of mental workload associated with using the FreeDev application. Therefore, it can be concluded that most students perceive a medium level of mental workload when using the mobile application, which answers hypothesis H2. However, in Figure 3 the students' responses can be seen, these are concentrated in the values between 466.25 and 596.25, with very few students reaching a higher score, and only one student reached 770 points. This indicates that the students did not experience excessive mental workload when using the FreeDev application. Therefore, it is considered that this application can be used as a support for teaching basic programming.

V. DISCUSSION

A. OBJECTIVE 1

In recent years, there has been a notable shift in the way in which VR technology is being employed to enhance learning, particularly in the context of subjects that are abstract and

TABLE 6. NASA-TLX dimension pair analysis (Example student 1).

Students	MD-PD	MD-EF	MD-FL	MD-PE	MD-TD	PD-FL	PD-PE	PD-TD	PE-TD	EF-PD	FL-EF	FL-PE	EF-PE	FL-TD	TD-EF
MD	60	48	54	54	44	-	-	-	-	-	-	-	-	-	-
PD	-	-	-	-	-	16	7	9	-	3	-	-	-	-	-
TD	-	-	-	-	16	-	-	51	25	-	-	-	-	32	32
PE	-	-	-	6	-	-	53	-	35	-	-	47	23	-	-
EF	-	12	-	-	-	-	-	-	-	57	37	-	37	-	28
FL	-	-	6	-	-	44	-	-	-	-	23	13	-	28	-

TABLE 7. NASA-TLX evaluation Table (Example student 1).

Student 1	A) Weight	B) Score	C) Converted score (B x 5)	D) Weighted Score (C x A)
MD	5	9	45	225
PD	0	1	5	0
TD	4	8	40	160
PE	2	18	90	180
EF	3	6	30	90
FL	1	2	10	10
Total	15	44	220	665

TABLE 8. NASA-TLX scoreboard.

NASA-TLX	Mental Workload Level
Score less than or equal to 500 points	28 students (Low)
Score greater than 500 points and less than 1,000 points	32 students (Medium)
Score over 1,000 points	0 (High)

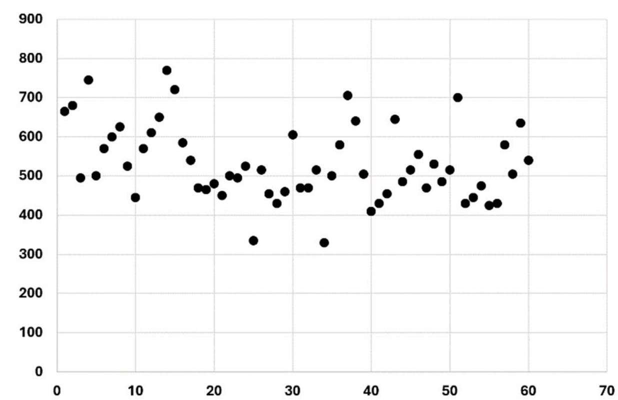

FIGURE 3. Responses of the 60 participants to the NASA-TLX survey.

challenging to grasp [28], [32]. The increase in test scores on programming concepts after using a VR application raises an interesting discussion about the impact technology has on education, specifically in teaching technical disciplines such as programming. When students use a VR application to improve their programming skills and then see an improvement on a knowledge test, it can be stated, with an experiential example, that technology is revolutionizing the educational model. This can be translated into a perception of usefulness, which demonstrates the potential and effectiveness of the application using VR in the educational environment. The favorable results suggest that both teachers and students can use technology as a useful and beneficial tool for the teaching and learning process. This positive result in the pre- and post-test methodology can be attributed to several factors, such as the application's ability to facilitate the understanding of complex concepts, its ability to improve student motivation and engagement, and its ability to provide a more interactive and engaging learning experience.

FreeDev enables users to navigate a virtual environment conducive to experimental programming practices. In contrast to conventional methods, which typically involve the mere display of code lines on a screen, this technology affords users the capability to visualize the software's internal workings and engage with it in a manner reminiscent of gaming experiences. This makes understanding the concepts much easier and more entertaining. In addition, the interactivity provided by this application can encourage more active learning. Students can participate in hands-on activities and directly experience the results of their code, giving them immediate feedback on their learning outcomes. This teaching approach is student-centered, and could increase motivation and engagement in learning, which in turn could translate into improved academic performance.

Another important aspect is how to integrate the VR application into the existing programming curriculum. VR should not be used as a complete substitute for other teaching methods, but rather as a complementary tool that enriches the educational experience. The integration of VR with other pedagogical approaches, including project-based learning, gamification, and teacher-directed instruction, can enhance its efficacy and facilitate comprehensive learning.

B. OBJECTIVE 2

The results of the students' perception of the mental workload assessment using the NASA-TLX tool provide valuable information on the use of VR technology to support education. In this research, it could be observed that the highest rating of the questionnaire was obtained by the dimension of PE. Meaning that, students felt confident with the performance shown when completing the tasks requested by the application. The dimension dealing with mental demand yielded results indicating significant effort and concentration when completing the tasks assigned by the application. The assessment obtained for time demand indicates that in the assigned tasks there was some pressure to complete the activities on time. The rating of effort expended suggests that students did not overexert themselves in the requested activities. The frustration level was perceived as low, indicating that students did not feel frustrated during the assigned tasks. Finally, there is no physical demand, as when using the VR application students did not perceive a physical work to perform. Students experienced moderate mental workload on task, with high PE and low levels of frustration. Time pressure and mental demand appear to have been important factors. These findings may help to design future tasks and adjust workload to improve students' performance and satisfaction, considering their individual needs and abilities. Furthermore, although the overall result of the mental workload in the use of the application was medium, it could be observed that most of the data were contained between the values of 460 and 597. Since the results are very close to 500, which is the maximum value of a low mental workload, we can affirm that the FreeDev application can be used as a support in programming education.

These results can be compared with the research by Sankaran, et. al. [66], which utilized a mixed reality application for medical training on sepsis prevention. Both studies show that students perceive they can perform well with the applications, although the performance score in FreeDev is slightly lower than in the medical application. The MD is similar in both studies, indicating that students initially find the task demanding. The PD in FreeDev is significantly lower, indicating that students perceive almost no physical demand when using the application. The TD is similar in both studies, showing that students feel low time pressure to complete the tasks. The FL is significantly lower in FreeDev, indicating that students experience less frustration when using the application. The EF is lower in FreeDev, suggesting that students find the application less mentally demanding.

Comparing both studies, it is observed that students find the use of FreeDev less frustrating, and less PD compared to the medical applications evaluated. The MD and TD are comparable between both studies, while the PE and EF are slightly lower in FreeDev. These results indicate that FreeDev provides an effective user experience without overloading students mentally or physically.

C. OBJECTIVE 3

Due to the rapid growth in the use of this immersive technology in various fields, including education, it is important to pay attention to problems related to health impact. These may be due to prolonged use of VR glasses, which can cause visual fatigue, manifesting as eyestrain, blurred vision, or headache [67], [68]. Furthermore, that one may experience, depending on the student, dizziness and nausea when using VR technology, especially when virtual movements do not match real body movements (such as in action games) [30], [69]. Alternatively, this technology can cause physical discomfort, including cold sweats, vertigo, and feelings of disorientation. For some people, immersion in virtual environments can cause stress and anxiety, especially if the environments are very realistic or involve stressful situations [30], [67]. Prolonged use of VR devices can lead to awkward or unhealthy postures, which can cause muscle and joint discomfort [67], [70].

For these reasons, it is important to address these health issues proactively when designing and using VR technology. Educational experiences should be designed to be intuitive, easy to use, and not overload the student with unnecessary information. Moreover, they should minimize the possibility of causing dizziness, nausea, or other discomfort. This should include optimizing graphics, speed of movement and interaction with the virtual environment.

It would be beneficial for students to have the ability to modify application settings, including the speed of movements, color, contrast, sound, and intensity of visual effects. Such an approach would enhance the intension of use of the applications and personalize the learning according to the individual preferences and needs of the students.

It is recommended that students undergo preliminary training to become accustomed to the VR experience and reduce the possibility of discomfort. Additionally, it is recommended that students be gradually introduced to immersive environments, with brief initial sessions and subsequent increases in duration.

Mechanisms for students to report any discomfort experienced during VR use should be incorporated to improve the design and minimize negative effects. In this way, educational methodologies can be further developed to improve the comfort and safety of the VR experience, with the goal of making it more accessible and enjoyable for a greater number of people.

Finally, it is important to provide frequent breaks and breaks to limit continuous use to avoid physical, visual, and mental fatigue. This will provide educational environments, with VR technology, that generate a safe and healthy experience.

VI. CONCLUSION

Based on the results of the pre-test and post-test methodology, it is possible to indicate that the use of the FreeDev application proved to be effective in improving the students' understanding of basic programming.

Although the mental workload, as measured by the NASA-TLX tool, was moderate and did not reach the anticipated low levels, the values obtained remained relatively close to the low load range. This suggests that, despite the perception of some difficulty, students did not experience excessive mental workload when using the FreeDev application. It is therefore crucial to establish a framework for the design of VR pedagogical tools that effectively balances mental workload with learning effectiveness.

It can be posited that the utilization of VR technology in an educational context may prove an efficacious method of enhancing comprehension of intricate concepts. However, it is also evident that this approach may present certain challenges, particularly in relation to the mental and temporal demands placed upon students, as well as the perceived effort required. As immersive technologies are being used to innovate the educational model, consideration should be given to factors that influence the use of these technologies, e.g., attention span, students' learning style, accessibility, educational content, security and privacy, and cost-effectiveness associated with the use of this technology. It is crucial to propose recommendations to improve the learner experience, such as incorporating regular breaks during application use or implementing support features to reduce frustration in the use of immersive technologies.

VII. FUTURE WORK

Future research could focus on improving the user experience when using the VR application. This should be achieved by investigating how to simplify the interface, improve the instructions and provide clearer feedback and thereby reduce the perceived mental workload of the students. Furthermore, it is essential to integrate into the application, the mechanisms that detect the discomfort of the students through the recognition of gestures, it is with the objective of improving the design of immersive application.

Also, future research should focus on the analysis of the training prior to the use of the application, and whether it can assist students to become familiar with the technology and reduce the mental workload associated with the use of VR technology. It is crucial to examine how to design educational activities within the VR application, such as breaking tasks into smaller steps or providing contextual aids, and to assess the impact this may have on the perception of mental workload. It could be identified how to integrate this technology with teaching and learning programming strategies to identify the relative advantages and disadvantages.

Finally, it should be studied how to make the VR application more accessible to people with disabilities, and which can be adapted to different learner profiles, such as those with different levels of programming experience or with special educational needs.

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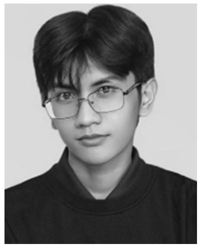

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