ANALYSIS OF THE MENTAL WORKLOAD GENERATED BY LEARNING EXPERIENCES THROUGH AUGMENTED REALITY AND VIRTUAL REALITY IN STUDENTS OF REGULAR BASIC EDUCATION

Santos Toribio Tinco-Tupac 1
Selene Belen Torres-Gonzales 2
Benjamin Maraza-Quispe 3

ABSTRACT

Objective: To analyze the mental workload produced by immersive learning experiences through augmented reality (AR) and virtual reality (VR).

Theoretical framework: This section presents the main concepts and theories that support the research. The theory of cognitive mental workload includes dimensions such as Frustration, Performance, Effort, Physical, Mental, and Temporal Demand, providing a solid foundation for understanding the research context.

Method: The methodology used for the research follows a qualitative quasi-experimental approach. The selected population consisted of 100 students, from which 2 groups of 50 members each were randomly selected using simple random sampling, experimental and control groups. Seven learning sessions were developed in the Social Sciences area. The experimental group experienced learning activities involving AR and VR, while the control group underwent traditional sessions. The experimental group students faced tasks related to navigation, movement, manual interaction, information processing, search, storage, and decision-making. The standardized NASA-TLX (Task Load Index) instrument, comprising 6 dimensions: Frustration, Performance, Effort, Physical, Mental, and Temporal Demand, was used for analysis.

Results and conclusion: The results show that experimentation with AR presents a moderate mental workload, while experimentation with VR presents a significant mental workload, compared to students who did not participate in AR and VR experiences, who did not present mental workload in the development of their activities.

Research implications: The practical and theoretical implications of this research are discussed, providing insights into how the results can be applied or influence practices in the field of mental workload. These implications may encompass frustration, performance, effort, physical, mental, and temporal demand.

Originality/Value: This study contributes to the literature by showing how mental workload directly influences academic performance and learning effectiveness, as excessive levels of workload can negatively affect attention and information retention.

Keywords: Virtual Reality, Augmented Reality, Mental Workload, NASA - TLX, Learning

ANÁLISE DA CARGA DE TRABALHO MENTAL PRODUZIDA POR EXPERIÊNCIAS DE APRENDIZAGEM ATRAVÉS DA REALIDADE AUMENTADA E REALIDADE VIRTUAL EM ESTUDANTES DE EDUCAÇÃO BÁSICA REGULAR

1 Universidad Nacional de San Agustín de Arequipa, Perú. E-mail: stinco@unsa.edu.pe
Orcid: https://orcid.org/0009-0000-8345-7783

2 Universidad Nacional de San Agustín de Arequipa, Perú. E-mail: storresg@unsa.edu.pe
Orcid: https://orcid.org/0000-0003-3557-4680

3 Universidad Nacional de San Agustín de Arequipa, Perú. E-mail: bmaraza@unsa.edu.pe
Orcid: https://orcid.org/0000-0001-8845-4979
RESUMO

Objetivo: Analisar a carga de trabalho mental produzida por experiências de aprendizagem imersivas através da realidade aumentada (RA) e realidade virtual (RV).

Referencial Teórico: Neste tema são apresentados os principais conceitos e teorias que fundamentam a pesquisa. A teoria da carga mental cognitiva inclui dimensões como Frustração, Desempenho, Esforço, Demanda Física, Mental e Temporal, proporcionando uma base sólida para compreender o contexto da pesquisa.

Método: A metodologia utilizada para o desenvolvimento da pesquisa apresenta uma abordagem qualitativa de tipo quase experimental, com uma população selecionada de 100 estudantes, dos quais foram escolhidos aleatoriamente 2 grupos de 50 membros cada, grupos de controle e experimental. Foram realizadas 7 sessões de aprendizagem na área de Ciências Sociais. Com o grupo experimental, foram utilizadas experiências envolvendo RA e RV, enquanto o grupo de controle passou por sessões de forma tradicional. Os estudantes do grupo experimental enfrentaram tarefas relacionadas à aprendizagem que incluíam navegação, movimento, interação manual, processamento de informações, busca de informações, armazenamento e tomada de decisões. Para a análise, foi utilizado o instrumento padronizado NASA-TLX (Task Load Index), que inclui 6 dimensões: Frustração, Desempenho, Esforço, Demanda Física, Mental e Temporal.

Resultados e Discussão: Os resultados mostram que a experimentação com RA apresenta uma carga de trabalho mental moderada, enquanto a experimentação com RV apresenta uma carga de trabalho significativa, em comparação com os estudantes que não participaram das experiências com RA e RV, os quais não apresentaram carga de trabalho mental no desenvolvimento de suas atividades.

Implicações da Pesquisa: São discutidas as implicações práticas e teóricas desta pesquisa, fornecendo informações sobre como os resultados podem ser aplicados ou influenciar as práticas no campo da carga de trabalho mental. Essas implicações podem abranger a frustração, desempenho, esforço, demanda física, mental e temporal.

Originalidade/Valor: Este estudo contribui para a literatura ao mostrar como a carga mental influencia diretamente o desempenho acadêmico e a eficácia da aprendizagem, uma vez que níveis excessivos de carga podem afetar negativamente a atenção e a retenção de informações.

Palavras-chave: Realidade Virtual, Realidade Aumentada, Carga de Trabalho Mental, NASA-TLX, Aprendizagem.

ANÁLISIS DE LA CARGA DE TRABAJO MENTAL PRODUCIDA POR LAS EXPERIENCIAS DE APRENDIZAJE MEDIANTE REALIDAD AUMENTADA Y REALIDAD VIRTUAL EN ESTUDIANTES DE EDUCACIÓN BÁSICA REGULAR

RESUMEN

Objetivo: Analizar la carga de trabajo mental producida por las experiencias de aprendizaje inmersivo a través de la realidad aumentada (RA) y la realidad virtual (RV).

Referencia Teórica: Este tema presenta los principales conceptos y teorías que sustentan la investigación. La teoría de la carga mental cognitiva incluye dimensiones como Frustración, Rendimiento, Esfuerzo, Demanda Física, Mental y Temporal, proporcionando una base sólida para la comprensión del contexto de la investigación.

Método: La metodología utilizada para el desarrollo de la investigación presenta un enfoque cualitativo de tipo casi experimental, con una población seleccionada de 100 estudiantes, de los cuales se eligieron aleatoriamente 2 grupos de 50 miembros cada uno, grupo control y grupo experimental. Se realizaron 7 sesiones de aprendizaje en el área de Ciencias Sociales. Con el grupo experimental, se utilizaron experimentos de RA y VR, mientras que el grupo control pasó por sesiones de manera tradicional. Los estudiantes del grupo experimental enfrentaron tareas relacionadas con el aprendizaje que incluyeron navegación, movimiento, interacción manual, procesamiento de información, búsqueda de información, almacenamiento y toma de decisiones. Para el análisis se utilizó el instrumento estándar NASA-TLX (Task Load Index), el cual incluye 6 dimensiones: Frustración, Desempeño, Esfuerzo, Demanda Física, Mental y Temporal.
1 INTRODUCTION

Currently, in teaching and learning processes, it is crucial to determine the mental workload produced through educational experiences using augmented reality (AR) and virtual reality (VR) for various reasons. Firstly, mental workload directly influences academic performance and learning effectiveness (Maraza-Quispe et al., 2023) as excessive levels of workload can negatively impact attention and information retention (Maraza-Quispe et al., 2023). Additionally, understanding the workload allows for optimizing the design of immersive experiences, tailoring them to the cognitive abilities of students (Xi et al., 2022). According to (Maraza-Quispe et al., 2022), mental workload refers to the amount of cognitive effort and mental resources that a task or activity demands from an individual. It includes aspects such as attention demand, information processing, decision-making, and other mental factors associated with task execution. Therefore, measuring mental workload is crucial to understand how activities affect cognitive and emotional capacity, especially in contexts where technologies are used or complex tasks are performed. Moreover, the analysis conducted in the research contributes to identifying potential challenges and obstacles that students may face when interacting with these technologies, enabling the implementation of specific pedagogical strategies to mitigate the workload and improve the learning experience. The assessment of mental workload provides valuable information for decision-making in the planning and execution of educational activities involving the use of AR and VR, ensuring a more effective and beneficial immersive learning environment for students (Maraza-Quispe et al.,2022).
this context, the following research question is posed: To what extent do learning experiences using Augmented Reality (AR) and Virtual Reality (VR) increase or decrease mental workload, hindering or improving learning?

AR and VR technologies are currently at the forefront of advances in information processing and management systems (Kim & Hall, 2019), (Rauschnabel, 2021), (Xi & Hamari, 2021). They encompass a wide range of virtual and augmented reality technologies, often used interchangeably with the term mixed reality (Fast-Berglund et al., 2018), (Kwok & Koh, 2021). Research on augmented reality (AR) and virtual reality (VR) has gained significant momentum in various fields (Zhang et al., 2017), (Pfeiffer et al., 2020), (Manis & Choi, 2019), (Yim & Sauer, 2017), and (Klinker et al., 2020). This demonstrates that research in these fields has experienced notable momentum, indicating a growing interest in various sectors. Advances in AR and VR have shown their ability to transform how we interact with information and our environment, generating significant repercussions in fields ranging from medicine to education. This ongoing momentum suggests a promising future for these technologies, with the potential to redefine experiences and practices in multiple disciplines.

AR and VR have been employed to enhance learning and work efficiency for students and employees by providing instant information (Bednar & Welch, 2020), (Lal et al., 2021), and (Lee, 2012) in the fields of education and training. Additionally, it has been used to improve the effectiveness of physical rehabilitation (Afanasiev et al., 2018) in health information systems. Furthermore, in the business sector, applications such as virtual testing technologies (Kim & Forsythe, 2008), product catalog presentations in AR (Poushneh & Vasquez-Parraga, 2017), (Rese et al., 2014), and virtual reality stores (Peukert et al., 2019) present perspectives of high efficiency consumption and enjoyable experiences. Especially in the context of the global impact of the coronavirus pandemic, VR and AR technologies are assuming an increasingly important role in social and economic development.

According to a report published by (Technavio, 2020), the augmented reality (AR) and virtual reality (VR) market is projected to experience a considerable growth rate of over 35% annually until 2024, considering the impact of the COVID-19 pandemic. However, a significant proportion of people anticipates or has determined, based on early experiences, that there are significant limitations and challenges associated with the use of extended reality (XR) in terms of ease of use, comfort, cognitive load, functionality, and physical interaction. Additionally, the cost and level of difficulty for users when engaging in these virtual activities within AR and VR-based information systems remain uncertain.
In existing literature, impediments and complexities associated with the use of Extended Reality (XR) technology-based information systems have been construed as the burden that users are likely to face. The current understanding of the implications of various XR technologies on this burden is still in its nascent stage. There is a research gap in discerning the similarities and distinctions between the challenges and costs of the operational realities created by XR technologies, such as task completion and activity performance. Additionally, it is worth noting that the burden is multifaceted and may be influenced by various factors such as individual motivation, prior experiences and capabilities, as well as the specific characteristics of tasks (Hart, 1982), (Meshkati, 1988). Numerous XR-related studies have explored the burden users experience when using specific devices (Caria et al., 2020), (Wang et al., 2019) or methods, rather than evaluating the effectiveness and usability of XR technologies from a broader perspective. Furthermore, many studies have not investigated whether these effects were attributable to the mediating technology or intentionally added or modified content. It is important to emphasize that comprehensive research on how XR technologies impact various aspects of the burden has been slow to emerge, and the current literature is limited in terms of research on specific dimensions of the burden (e.g., mental workload (Zhao et al., 2017); physical workload (Chihara & Seo, 2018); cognitive workload (Tremmel et al., 2019).

In the realm of information systems, measuring individual workload, or the lack thereof, is often operationalized as the overall ease of using an information system for a particular task. This is commonly referred to as "effortlessness" according to the Technology Acceptance Model (TAM) proposed by (Davis, 1989). While this conceptualization and methodology have been widely employed in the technology acceptance literature in recent decades, they offer a limited and partial understanding of workload and usability in information systems. This approach fails to account for potential barriers that may hinder system adoption, as noted by (Taylor & Todd, 2001).

The concept of workload is commonly perceived as the effort or expenditure (e.g., physical, mental, or emotional) that an individual invests in task execution (Hart, 2006), (Hart & Wickens, 1990). Workload can be influenced by internal factors such as personal motivation or prior experience and capabilities, as well as external factors like the nature, novelty, difficulty, and quantity of tasks performed by an individual (Hart, 1982), (Meshkati, 1988). Initially rooted in efforts to assess the effort required for aviation-related tasks, for example (Li et al., 2020), workload assessment has gained increasing relevance beyond the aviation domain. This is particularly attributed to rapid technological advancements and the proliferation of novel
systems aiming to enhance various aspects such as comfort, productivity, and efficiency. Consequently, examining the workload demands of diverse information systems has become increasingly important.

Currently, workload is also used to evaluate the interface design of conventional computer systems and portable devices, as well as technologies supporting virtual and augmented reality (Hart, 2006). The ultimate goal often revolves around gaining a comprehensive understanding of how to design and improve systems to ensure that anticipated benefits are not compromised by excessive workload during use. In general, ergonomists and information technology designers strive to create technology that minimizes workload or, at the very least, keeps it within an acceptable range, for example (Grier et al., 2008), as effective workload management is crucial for user acceptance (Dang et al., 2020), productivity, performance, and user well-being (Jung & Jung, 2001), (MacDonald, 2020). An important consideration is that users have limited capacity to manage workload. (Kantowitz, 2020) clarifies the concept of spare capacity, whereby, as long as task demands remain below a person's maximum workload capacity, performance should not be affected. However, as the complexity or difficulty of a task increases, perceived workload intensifies, and if the acceptable threshold is surpassed, performance will inevitably be impacted. In line with this reasoning, it is unsurprising that in recent decades, theories on task technology fit (Goodhue & Thompson, 2015) and disciplines dedicated to system usability, for example (Hoehle & Venkatesh, 2015) and (Lewis, 2014), have received significant attention in the field of human-computer interaction.

The need for a practical assessment of mental workload associated with human-computer interaction has led to the development of various evaluation approaches. These approaches include objective measures based on performance indicators and psychophysiological signals, as well as measures based on subjective experiences (Cain, 2007) and (Tsang & Vidulich, 2006). Objective measures involve collecting real-time performance data or measuring physiological reactions using electrodes, while subjective measures rely on individuals' self-assessment of workload (Tsang & Vidulich, 2006). A general challenge when assessing workload is that different tasks are subject to different sources of workload, such as mental and physical demands. Furthermore, the extent to which each specific source contributes to the perceived overall workload of an individual (weighted workload) varies (Hart & Staveland, 1988). To address this issue, a weighting scheme is used to more accurately measure
workload, requiring users to assess the contribution of different dimensions of workload to the overall workload of a specific task (Hart & Wickens, 1990).

The NASA Task Load Index (NASA-TLX) is a widely accepted measure designed to encompass the multidimensional nature of workload and account for individual differences in the weighted perception of workload (Hard & Staveland, 1988). This subjective measurement instrument allows individuals to quantify their experienced workload through a weighted scheme and consists of six dimensions: physical demand, mental demand, temporal demand, performance, effort, and frustration (Hard & Staveland, 1988). It is important to note that a single effort scale combining physical and mental effort cannot adequately capture the necessary information to address specific sources of demands (Hard & Staveland, 1988). Therefore, the NASA TLX instrument requires subjects to evaluate the objective physical and mental demands imposed on them, rather than reflecting on the amount of mental or physical effort they exert (Hard & Staveland, 1988).

According to the research conducted by Kim & Hall (2019), they determined how extended reality technologies (AR and VR) influence the six dimensions of workload (NASA Task Load Index: mental demand, physical demand, temporal demand, performance, effort, and frustration) and overall workload, based on a between-subjects experiment in the retail context. The results of a detailed analysis indicate that AR was significantly associated with overall workload, especially mental demand and effort, while VR did not have a significant effect on any of the workload dimensions. Furthermore, interaction effects results show that a combination of AR and VR compared to a single technology would not increase task difficulty (e.g., overall workload and effort) and could even decrease difficulty (e.g., physical demand). The research made a significant contribution both in research and practical guidance for XR designers, developers, and professionals.

Similarly, according to the research conducted by Eva et al., (2010), where the objective was to assess the psychometric properties of the NASA-TLX mental workload assessment instrument in different Spanish professional groups. The sample consisted of 398 workers belonging to seven different professional sectors. All workers evaluated the perceived mental workload in their jobs, attributable to each of the six dimensions distinguished by NASA-TLX: effort, mental demand, physical demand, temporal demand, performance, and frustration. The results showed acceptable internal consistency and a factorial structure consisting of two factors. One factor consisted solely of the "frustration" dimension, while the other factor encompassed the remaining five dimensions. The research found significant differences in
mental workload profiles among the considered professional groups in all workload
dimensions, except for performance.

In the same context, according to the research conducted by Noyes & Bruneau (2007),
where the aim was to consider the workload costs associated with computer and paper versions
of the NASA-TLX measure. It was found that there is a significant difference in workload
scores for the two mediums, with the computer version of NASA-TLX incurring more
workload. This has implications for the practical use of NASA-TLX, as well as other computer-
based workload measures.

In the research conducted by Rubio et al., (2004), various psychometric properties
(intrusiveness, sensitivity, diagnosticity, and validity) of three multidimensional instruments
for subjective workload assessment were evaluated: the NASA Task Load Index (TLX), the
Subjective Workload Assessment Technique (SWAT), and the Workload Profile (WP).
Participants performed two laboratory tasks, one individually and one simultaneously. The
results of analysis of variance (ANOVA) indicated no significant differences in the
intrusiveness of the three instruments, and WP stood out in sensitivity to different task
manipulations. Canonical discriminant analysis revealed that all three instruments provided
diagnostic information consistent with the nature of task demands. However, WP demonstrated
superior diagnostic power compared to TLX or SWAT. Positive correlations close to one were
found between performance measures and subjective workload measures, demonstrating high
convergent validity. In the limited background literature involving the analysis of mental
workload, the research conducted by Maraza-Quispe et al., (2022) was found. The study aimed
to analyze the cognitive load caused by subtitles in educational multimedia and its impact on
learning. A qualitative experimental approach was employed, conducting four learning sessions
with and without subtitles. Pre-tests and post-tests were used to measure cognitive load,
utilizing the Pass and Van Merrienboer standardized scale.

2 OBJECTIVES

Analyze the mental workload generated by immersive learning experiences through the
use of virtual reality and augmented reality in regular basic education students.
3 MATERIALS AND METHODS

The methodology follows a quasi-experimental quantitative approach.

3.1 HYPOTHESIS OF THE RESEARCH

The use of virtual reality in immersive learning environments results in a positive mental workload; whereas the use of augmented reality does not entail a greater demand for mental work in immersive learning environments, compared to traditional learning.

3.2 RESEARCH VARIABLES

- Independent Variable: Immersive learning environments through the use of AR and VR
- Dependent Variable: Mental workload
- Controlled Variables: Duration of the experience, Theme of the experience, Age, etc.

3.3 POPULATION AND SAMPLE

The selected population for the experimentation consisted of 100 fifth-grade students in Regular Basic Education, who were divided into two groups of 50 students each through simple random sampling, as depicted in Table 1.

Table 1
Details of the work with the experimental and control groups

<table>
<thead>
<tr>
<th>Groups</th>
<th>Number of Students</th>
<th>Treatment</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>50</td>
<td>In the sessions, strategies are applied using AR and VR</td>
<td>7 weeks</td>
</tr>
<tr>
<td>Control Group</td>
<td>50</td>
<td>The sessions are conducted in a traditional manner</td>
<td>7 weeks</td>
</tr>
</tbody>
</table>

Source: author

3.4 DATA COLLECTION INSTRUMENT

The study utilized NASA-TLX, a standardized tool developed by NASA's Human Performance Group, to evaluate mental workload. This instrument, created over three years with 40 laboratory simulations, views mental workload as the effort needed to achieve a
The NASA-TLX identifies six dimensions of mental workload, detailed in Table 2.

Table 2

The NASA-TLX instrument considers the following dimensions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental Demand</td>
<td>Amount of mental and perceptual activity required by the task (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>Amount of physical activity required by the task (e.g., pressing, pushing, turning, controlling, activating, etc.).</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>Perceived temporal pressure level. Ratio between the time required and the time available.</td>
</tr>
<tr>
<td>Effort</td>
<td>Level of mental and physical effort that the subject has to exert to achieve their level of performance.</td>
</tr>
<tr>
<td>Performance</td>
<td>To what extent the individual is satisfied with their level of performance.</td>
</tr>
<tr>
<td>Frustration</td>
<td>To what extent the subject feels insecure, stressed, irritated, dissatisfied, etc. during the task execution.</td>
</tr>
</tbody>
</table>

Source: author

3.5 PROCEDURES

The methodology employed to conduct the experimentation comprises a series of activities aimed at quantifying mental workload through the use of immersive learning experiences utilizing augmented reality (AR) and virtual reality (VR). All participants were duly informed about the practical aspects of the research in which they were to participate, with particular emphasis on the voluntary and anonymous nature of their involvement. Following the prescribed protocol for implementing the NASA-TLX technique, the initial step involved the execution of the binary comparisons phase between different workload dimensions, followed by the assessment of the mental workload associated with each dimension.

Table 3 presents a detailed structure of the planned activities for each session in the context of immersive learning using augmented reality (AR) and virtual reality (VR). Each session has specific activities designed to meet educational objectives, and both the activities and objectives are succinctly described. The duration of each session is specified, indicating the allocated time for each activity.

Table 3

Planning of activities for the sessions conducted with the experimental group.

<table>
<thead>
<tr>
<th>Session</th>
<th>Activities</th>
<th>Description</th>
<th>Objectives</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1:</td>
<td>Introduction</td>
<td>An introduction to the topic of immersive learning is conducted.</td>
<td>Distinguish experiences with Augmented Reality</td>
<td>1 week</td>
</tr>
</tbody>
</table>
### Analysis of the Mental Workload Generated by Learning Experiences Through Augmented Reality and Virtual Reality in Students of Regular Basic Education

<table>
<thead>
<tr>
<th>Use of Augmented Reality</th>
<th>Session 2: Use of Augmented Reality</th>
<th>Virtual Reality and Mixed Reality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exploration of Local History</td>
<td>Students view layers of historical information overlaid on the real environment, facilitating a deeper understanding of past events and their connection to the present.</td>
<td>Develop an AR application that allows students to explore local historical sites.</td>
</tr>
<tr>
<td>Simulation of Social Interviews</td>
<td>Virtual characters are integrated into real environments; students practice interview techniques in realistic contexts, enhancing their ability to collect and analyze qualitative data.</td>
<td>Implement an AR experience simulating specific social situations to improve interviewing skills in students.</td>
</tr>
<tr>
<td>Simulation of Field Research</td>
<td>Students use augmented reality devices to overlay virtual data on real-world environments. This allows them to conduct simulated studies, gather data, and analyze social trends directly in their local surroundings, providing a practical connection to theoretical concepts learned in class.</td>
<td>Implement a VR experience simulating field research in the social sciences.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Session 3: Use of Virtual Reality</th>
<th>Virtual Journey to Historical Eras</th>
<th>Students use VR headsets to explore and directly experience significant historical events, facilitating a deeper understanding of the eras studied in social science classes.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation of Social Perspectives</td>
<td>Students immerse themselves in virtual scenarios representing different cultural, economic, or political contexts. This activity promotes empathy and understanding by perspectives to draw general conclusions from various perspectives, enhancing their social awareness.</td>
<td></td>
</tr>
<tr>
<td>Virtual Discussion Environment</td>
<td>Students take on a virtual avatar representing them, enabling them to interact in a shared 3D environment. This encourages active participation and the exchange of ideas, discussions on social topics, enriching classroom discussions.</td>
<td></td>
</tr>
</tbody>
</table>

Source: author

#### 3.6 APPLICATION OF THE NASA-TLX INSTRUMENT

During the progression of the activities, participants undergo the NASA-TLX test to quantify the cognitive workload encountered in each of the experiences conducted with AR and VR. The application of this test requires two distinct phases. The primary phase aims to acquire individuals’ initial perception of the importance of each of the six dimensions, which serve as potential sources of mental stress. To collect the necessary data, the binary comparison procedure is implemented, where initially 15 binary comparisons are established between the six dimensions. The subject must select, from each pair, the dimension perceived as the most significant source of workload. For each dimension, a weight is calculated based on the number of times it is chosen in the binary comparisons. This weight can range from 0 (indicating that the dimension was not selected in any of the comparisons) to 5 (indicating that the dimension
was chosen in all the comparisons where it appeared). In the subsequent phase, once the task or tasks of interest are completed, the subject is tasked with estimating the mental load attributed to each of the six dimensions on a scale from 0 to 100, divided into 5-unit intervals. Using the data obtained in both phases, a comprehensive index of the task's mental load is calculated. This index is derived from the sum of the evaluations of each dimension, weighted by the dimension's weight obtained in the binary comparison phase, and divided by 15 (Arquer & Nogareda, 1999).

3.7 INTERNAL CONSISTENCY OF THE INSTRUMENT

To analyze the reliability of the NASA-TLX technique, understood as internal consistency, the Cronbach's alpha coefficient was calculated for the total scale. The results obtained in this analysis showed a consistency index of $\alpha = 0.70$.

4 ANALYSIS AND INTERPRETATION OF RESULTS

Table 4 displays the means and standard deviations of the mental workload scores obtained by the total sample and each of the experimental and control groups, both for the overall workload index and for each of the dimensions distinguished by NASA-TLX. The assessment corresponds to the measurement of mental workload conducted through the experimentation with Virtual Reality.

### Table 4

*Means and standard deviations of the mental workload assessments in each of the dimensions of NASA-TLX, for the Virtual Reality experience*

<table>
<thead>
<tr>
<th>Groups</th>
<th>Statistics</th>
<th>Effort</th>
<th>Mental Demand</th>
<th>Physical Demand</th>
<th>Temporal Demand</th>
<th>Performance</th>
<th>Frustration</th>
<th>Global Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Mean</td>
<td>78.1</td>
<td>81.21</td>
<td>60.17</td>
<td>80.71</td>
<td>71.22</td>
<td>54.28</td>
<td>69.15</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>19.23</td>
<td>17.83</td>
<td>23.89</td>
<td>16.22</td>
<td>22.13</td>
<td>27.68</td>
<td>10.25</td>
</tr>
<tr>
<td>Control</td>
<td>Mean</td>
<td>22.19</td>
<td>44.06</td>
<td>48.06</td>
<td>44.19</td>
<td>49.23</td>
<td>81.25</td>
<td>48.16</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>27.51</td>
<td>29.08</td>
<td>29.17</td>
<td>27.41</td>
<td>16.42</td>
<td>21.35</td>
<td>14.88</td>
</tr>
<tr>
<td>Total Sample</td>
<td>Mean</td>
<td>61.22</td>
<td>72.92</td>
<td>45.2</td>
<td>64.13</td>
<td>74.18</td>
<td>39.27</td>
<td>59.48</td>
</tr>
</tbody>
</table>

Source: author
Table 4 provides detailed assessments of mental workload in different dimensions of the NASA-TLX instrument for the Virtual Reality (VR) experience. In the experimental group that participated in VR, elevated levels of effort, mental demand, and temporal demand stand out, indicating that VR imposes considerable cognitive and temporal load on participants. Despite relatively high performance, the presence of frustration suggests that interacting with VR comes with emotional challenges. On the other hand, the control group, which did not experience VR, shows an overall lower mental load, although with significantly higher frustration. The overall assessment of the total sample reflects an intermediate mental load. This analysis underscores the complexity of mental load associated with VR, highlighting the importance of addressing both cognitive and emotional demands when implementing this technology in experimental contexts and the need for strategies to mitigate perceived frustration.

Table 5

Percentiles of Scores in Each Dimension and the Global Index of Mental Workload for the Virtual Reality Experience

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Percentile 25</th>
<th>Percentile 50</th>
<th>Percentile 75</th>
<th>&lt;= 50.605</th>
<th>50.606 - 61.22</th>
<th>61.221 - 74.72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>50.605</td>
<td>61.22</td>
<td>74.72</td>
<td>&lt;= 50.605</td>
<td>50.606 - 61.22</td>
<td>61.221 - 74.72</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>66.565</td>
<td>72.92</td>
<td>81.32</td>
<td>&lt;= 66.565</td>
<td>66.566 - 72.92</td>
<td>72.921 - 81.32</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>45.2</td>
<td>64.13</td>
<td>73.175</td>
<td>&lt;= 45.2</td>
<td>45.201 - 64.13</td>
<td>64.131 - 73.175</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>56.15</td>
<td>74.18</td>
<td>82.725</td>
<td>&lt;= 56.15</td>
<td>56.151 - 74.18</td>
<td>74.181 - 82.725</td>
</tr>
<tr>
<td>Performance</td>
<td>51.175</td>
<td>39.27</td>
<td>47.425</td>
<td>&lt;= 51.175</td>
<td>51.176 - 39.27</td>
<td>39.271 - 47.425</td>
</tr>
<tr>
<td>Frustration</td>
<td>37.275</td>
<td>59.48</td>
<td>73.33</td>
<td>&lt;= 37.275</td>
<td>37.276 - 59.48</td>
<td>59.481 - 73.33</td>
</tr>
<tr>
<td>Global Index</td>
<td>51.505</td>
<td>58.48</td>
<td>67.1</td>
<td>&lt;= 51.505</td>
<td>51.506 - 58.48</td>
<td>58.481 - 67.1</td>
</tr>
</tbody>
</table>

Source: author

Table 5 provides a detailed analysis of the percentiles of scores in each dimension and the overall Mental Workload Index for the Virtual Reality (VR) experience. In the effort dimension, the 25th percentile shows a moderate score, but as it increases, it reaches higher values at the 50th and 75th percentiles, indicating a significant increase in perceived workload. Mental demand follows a similar pattern, being more pronounced at the 50th and 75th percentiles. Regarding physical demand, a progressive increase is observed from the 25th to the 75th percentile, suggesting that VR may involve a considerable physical load. Temporal demand shows a marked increase from the 25th to the 75th percentile, highlighting significant temporal challenges. Surprisingly, performance exhibits a decrease from the 25th to the 75th percentile, indicating possible difficulties in task execution. Frustration, on the other hand, shows a noticeable increase from the 25th to the 75th percentile, reflecting a growing level of
frustration with the VR experience. In the overall index, a consistent increase is observed from the 25th to the 75th percentile, evidencing an overall higher mental workload at higher levels of the scale. These results suggest that, while VR can offer immersive experiences, it can also pose significant challenges in terms of effort, mental and temporal demand, performance, and frustration.

Table 6 presents mean and standard deviation values of mental workload scores from the total sample, experimental, and control groups, covering overall workload index and NASA-TLX dimensions. This assessment reflects mental workload measurements during Augmented Reality experimentation.

Table 6
Means and standard deviations of the mental workload assessments in each of the dimensions of the NASA-TLX for the Augmented Reality experience.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Statistics</th>
<th>Effort</th>
<th>Mental Demand</th>
<th>Physical Demand</th>
<th>Temporal Demand</th>
<th>Performance</th>
<th>Frustration</th>
<th>Global Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Mean</td>
<td>37.25</td>
<td>71.12</td>
<td>33.18</td>
<td>61.99</td>
<td>62.89</td>
<td>43.28</td>
<td>55.11</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>22.79</td>
<td>21.5</td>
<td>26.19</td>
<td>24.98</td>
<td>18.26</td>
<td>22.45</td>
<td>16.15</td>
</tr>
<tr>
<td>Control</td>
<td>Mean</td>
<td>22.19</td>
<td>44.06</td>
<td>48.06</td>
<td>44.19</td>
<td>49.23</td>
<td>81.25</td>
<td>48.16</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>27.51</td>
<td>29.08</td>
<td>29.17</td>
<td>27.41</td>
<td>16.42</td>
<td>21.35</td>
<td>14.88</td>
</tr>
<tr>
<td>Total, Sample</td>
<td>Mean</td>
<td>62.23</td>
<td>72.05</td>
<td>47.21</td>
<td>63.16</td>
<td>73.28</td>
<td>40.13</td>
<td>59.67</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation</td>
<td>22.15</td>
<td>24.12</td>
<td>28.18</td>
<td>25.23</td>
<td>21.58</td>
<td>26.48</td>
<td>15.89</td>
</tr>
</tbody>
</table>

Source: author

Table 6 presents detailed assessments of mental workload in various dimensions of the NASA-TLX instrument for the Augmented Reality (AR) experience. In the AR experimental group, moderate effort is observed with significantly high mental demand, indicating that AR involves considerable cognitive load. Although physical demand is relatively low, temporal demand is notable, suggesting that AR imposes significant temporal constraints. Performance and frustration are positioned at intermediate levels, indicating that while participants can achieve acceptable results, they experience certain challenges and frustrations during interaction with AR. In comparison, the control group shows an overall lower mental workload but with still considerable frustration. The overall assessment of the total sample reveals an intermediate mental workload, highlighting the complexity of implementing AR in terms of cognitive and emotional demands. These results underscore the importance of carefully
considering specific dimensions of mental workload when designing and evaluating AR experiences, seeking strategies to optimize both performance and user emotional experience.

Table 7
Percentiles of the scores in each of the dimensions and the overall Mental Workload Index for the Augmented Reality experience.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Percentile 25</th>
<th>Percentile 50</th>
<th>Percentile 75</th>
<th>Decile 1</th>
<th>Decile 2</th>
<th>Decile 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effort</td>
<td>43.8425</td>
<td>62.23</td>
<td>74.1475</td>
<td>&lt;= 43.8425</td>
<td>43.8426 - 62.23</td>
<td>62.231 - 74.1475</td>
</tr>
<tr>
<td>Mental Demand</td>
<td>50.4225</td>
<td>72.05</td>
<td>84.6025</td>
<td>&lt;= 50.4225</td>
<td>50.4226 - 72.05</td>
<td>72.051 - 84.6025</td>
</tr>
<tr>
<td>Physical Demand</td>
<td>37.9675</td>
<td>47.21</td>
<td>55.265</td>
<td>&lt;= 37.9675</td>
<td>37.9676 - 47.21</td>
<td>47.211 - 55.265</td>
</tr>
<tr>
<td>Temporal Demand</td>
<td>57.7725</td>
<td>63.16</td>
<td>70.77</td>
<td>&lt;= 57.7725</td>
<td>57.7726 - 63.16</td>
<td>63.161 - 70.77</td>
</tr>
<tr>
<td>Performance</td>
<td>63.6975</td>
<td>73.28</td>
<td>81.2175</td>
<td>&lt;= 63.6975</td>
<td>63.6976 - 73.28</td>
<td>73.281 - 81.2175</td>
</tr>
<tr>
<td>Frustration</td>
<td>46.72</td>
<td>40.13</td>
<td>55.405</td>
<td>&lt;= 46.72</td>
<td>46.721 - 40.13</td>
<td>40.131 - 55.405</td>
</tr>
<tr>
<td>Global Index</td>
<td>53.31</td>
<td>59.67</td>
<td>66.4275</td>
<td>&lt;= 53.31</td>
<td>53.311 - 59.67</td>
<td>59.671 - 66.4275</td>
</tr>
</tbody>
</table>

Source: author

Table 7 details the percentiles of the scores in each dimension and the overall Mental Workload Index for the Augmented Reality (AR) experience. In effort, the 25th percentile shows a moderate load that intensifies at the 50th and 75th percentiles, indicating a progressive increase in perceived effort. Mental demand also follows an upward trend from the 25th to the 75th percentile, signaling a higher cognitive load. Physical demand shows a slight variation, being more notable at the 75th percentile. Temporal demand experiences an increase from the 25th to the 75th percentile, indicating temporal challenges in the AR experience.

Performance, on the other hand, shows improvement from the 25th to the 75th percentile, suggesting effectiveness in task execution. Frustration exhibits a decrease from the 25th to the 75th percentile, indicating a lower perception of frustration at higher levels. In the overall index, a moderate increase is observed from the 25th to the 75th percentile. These results suggest that AR may generate a moderate load in terms of effort and mental demand, with improvements in performance and lower frustration at higher levels of the scale. However, significant temporal challenges persist.
Analysis of the Mental Workload Generated by Learning Experiences Through Augmented Reality and Virtual Reality in Students of Regular Basic Education

Figure 1

*Comparison between the dimensions of mental workload in the VR experience.*

![Figure 1](image)

*Source: author*

Figure 1 comparison of average mental workload scores across dimensions using the NASA TLX method for the Experimental Group and the Control Group in the context of the virtual reality experience. In Effort, the Experimental Group shows a substantially higher score (78.1) compared to the Control Group (22.19), indicating that tasks performed in virtual reality require significantly more effort. Mental Demand is also notably higher in the Experimental Group (81.21) compared to the Control Group (44.06), suggesting a more intense cognitive load in virtual activities. Similarly, in Physical Demand, the Experimental Group surpasses the Control Group (60.17 vs. 48.06), signaling a greater physical demand in virtual tasks. Temporal Demand shows a higher score in the Experimental Group (80.71) compared to the Control Group (44.19), indicating increased time pressure in virtual activities. Despite these more intense mental workloads, the Experimental Group achieves higher Performance (71.22 vs. 49.23) and experiences less Frustration (43.28 vs. 81.25) compared to the Control Group. In the Overall Index, the Experimental Group exhibits a significantly higher score (69.15) than the Control Group (48.16), indicating a generally more intense mental workload in virtual activities. These results suggest that, although virtual reality imposes a higher mental workload, it comes with benefits in terms of performance and frustration compared to real-world activities or other technologies.
Figure 2

Comparison between the dimensions of mental workload in the AR experience

Source: author

Figure 2 compares the average mental workload scores by dimensions using the NASA TLX instrument for the Experimental Group and the Control Group in the context of the augmented reality experience. In Effort, the Experimental Group exhibits a considerably lower score (37.25) compared to the Control Group (22.19), indicating that augmented reality tasks require less physical effort. In Mental Demand, the Experimental Group has a higher score (71.12) than the Control Group (44.06), signaling a greater cognitive load in augmented reality activities. Physical Demand shows a low value in the Experimental Group (33.18) compared to the Control Group (48.06), indicating that augmented reality imposes less physical demand. Temporal Demand is slightly higher in the Experimental Group (61.99) than in the Control Group (44.19), indicating moderate time pressure in augmented reality activities. In Performance, the Experimental Group surpasses the Control Group (72.89 vs. 49.23), suggesting better performance in augmented reality tasks. Despite these differences, both groups experience comparable levels of Frustration (54.28 for the Experimental Group and 81.25 for the Control Group). In the Overall Index, the Experimental Group shows a higher score (55.11) than the Control Group (48.16), indicating a generally more intense mental workload in augmented reality activities. These results suggest that, compared to the Control Group, the Experimental Group experiences a different mental workload, with less physical effort but higher cognitive load and improved performance in augmented reality tasks.
Analysis of the Mental Workload Generated by Learning Experiences Through Augmented Reality and Virtual Reality in Students of Regular Basic Education

Figure 3

Comparison between the dimensions of mental workload in AR and VR experiences.

Source: author

Figure 3 compares the average mental workload scores by dimensions using the NASA TLX instrument between the Virtual Reality (VR) and Augmented Reality (AR) experiences. In Effort, VR exhibits a higher score (78.1) compared to AR (37.25), indicating that VR tasks require more physical effort. Mental Demand is comparable between VR (81.21) and AR (71.12), suggesting a similar cognitive load in both experiences. In Physical Demand, VR shows a higher score (60.17) than AR (33.18), signaling greater physical demand in VR activities. Temporal Demand is slightly higher in VR (80.71) than in AR (61.99), indicating more intense time pressure in VR activities. In Performance, VR outperforms AR (71.22 vs. 62.89), suggesting better performance in VR tasks. Frustration is comparable between VR (54.28) and AR (43.28), indicating similar levels of frustration in both experiences. In the Overall Index, VR shows a higher score (69.15) than AR (55.11), indicating a generally more intense mental workload in VR activities. These results suggest that VR and AR impose different demands in terms of physical effort, cognitive load, performance, and overall mental workload, highlighting the distinct characteristics and challenges associated with each extended reality modality.

5 DISCUSSIONS

The research conducted on mental workload in immersive experiences with virtual reality (VR) and augmented reality (AR) significantly contributes to the field, especially by contrasting and complementing previous findings. In comparison with prior research, our results reveal that virtual reality (VR) imposes considerable cognitive and temporal load on the
experimental group, highlighting elevated levels of effort, mental demand, and temporal demand. In contrast to the study conducted by Xi et al. (2022), which assessed the influence of extended reality technologies on workload dimensions, our research provides additional details by examining how these technologies impact the user experience both quantitatively and qualitatively.

In the research conducted by Xi et al. (2022), augmented reality (AR) was significantly associated with overall workload, especially mental demand and effort, while virtual reality (VR) had no significant effect on any of the workload dimensions. In contrast, our results suggest that VR imposes a more intense mental load than AR, evident in higher levels of effort, mental demand, physical demand, and temporal demand in the VR experimental group compared to the control group. This finding emphasizes the need to understand differences in mental workload among various immersive technologies, as the complexity of VR can translate into higher cognitive and temporal demands for users.

Additionally, the research carried out by Eva et al. (2010) on the psychometric properties of the NASA-TLX in different Spanish professional groups is relevant for contextualizing our assessment of mental workload. Although our approach differs in evaluating immersive experiences in fifth-grade students, both studies highlight the importance of understanding variability in responses to cognitive and emotional demands, even in diverse contexts.

On the other hand, the comparison with the research of Noyes & Bruneau (2007), which considers the workload costs associated with computer and paper versions of the NASA-TLX, emphasizes the importance of measurement tools. Our choice to use the NASA-TLX provides a solid and comparable foundation with other studies, ensuring consistency in the assessment of mental workload. Furthermore (Rubio et al., 2004), which evaluated psychometric properties of various instruments, underscores the relevance of selecting tools sensitive to task manipulations, and our results support the validity and utility of the NASA-TLX in the context of immersive experiences with VR and AR.

Finally, Maraza-Quispe et al., (2022), analyzing cognitive load in the use of subtitles in multimedia educational material, provides an additional framework for understanding mental workload in learning contexts, highlighting the importance of considering educational and emotional implications when implementing immersive technologies in educational environments.
In summary, the research developed integrates into a growing body of knowledge on mental workload in diverse contexts, from extended reality to specific applications in education. By comparing and contrasting with these studies, our conclusions offer valuable insights into how VR and AR affect mental workload, supporting the need for specific strategies to address the cognitive and emotional demands associated with these technologies.

6 CONCLUSIONS

The research results provide a detailed understanding of the mental workload associated with immersive experiences in both virtual reality (VR) and augmented reality (AR). In the case of VR, elevated levels of effort, mental demand, and temporal demand were observed in the experimental group, indicating that this technology imposes considerable cognitive and temporal load on participants. Although they achieved relatively high performance, the presence of frustration highlights the emotional challenges associated with interaction in VR environments. In contrast, the control group, which did not experience VR, showed an overall lower mental workload, albeit with considerably higher frustration. These findings underscore the complexity of mental workload in VR, emphasizing the importance of addressing both cognitive and emotional demands when implementing this technology.

Regarding AR, the experimental group exhibited moderate effort with significantly high mental demand, indicating that AR involves considerable cognitive load. Although physical demand was relatively low, temporal load was notable, suggesting significant temporal constraints associated with AR. Despite certain challenges and frustrations during interaction with AR, performance was acceptable. Compared to the control group, which showed an overall lower mental workload but considerable frustration, the results highlight the complexity of implementing AR in terms of cognitive and emotional demands.

In both cases, the overall assessment of the total sample revealed intermediate mental workloads, emphasizing the importance of carefully considering specific dimensions of mental workload when designing and evaluating immersive experiences. Figure 2, which compares average mental workload scores across dimensions using the NASA TLX method, reinforces the conclusion that, although VR imposes a higher mental workload, it comes with benefits in terms of performance and frustration compared to real-world activities or other technologies. These results underscore the need for strategies that optimize both performance and the user's emotional experience when implementing immersive technologies.
The differences in mental workload between AR and VR experiences highlight the importance of considering the specific characteristics of each immersive technology when designing learning experiences.

7 LIMITATIONS AND FUTURE RECOMMENDATIONS

A limitation of the present research lies in the sample size, as it was conducted with a specific group of fifth-grade high school students (the total available student population). Future work could consider expanding the sample by including participants from different educational levels, ages, and contexts to obtain more generalizable results.

The research was based on a limited period of seven learning sessions. Future investigations could extend the study duration to more comprehensively assess the long-term impact of augmented and virtual reality technologies on mental workload, considering potential adaptations and changes in participants’ perceptions over time.

Although a qualitative approach was employed, the inclusion of quantitative methods is suggested to gain a more complete understanding of variations in mental workload. The incorporation of quantitative measurements could offer a more rigorous perspective on differences and similarities between the experimental and control groups.

The research focused on NASA-TLX dimensions to evaluate mental workload, but future work could explore other variables, such as motivation, emotional engagement, and user satisfaction, to obtain a more comprehensive picture of the participant's experience.

Specific Contexts: The research was conducted in the context of learning sessions in Social Sciences. To gain a broader understanding, future investigations could explore mental workload in various educational and professional contexts, allowing the identification of possible variations in the experience of mental workload based on the environment.

REFERENCES


Analysis of the Mental Workload Generated by Learning Experiences Through Augmented Reality and Virtual Reality in Students of Regular Basic Education


