

Evaluating User Experience and Cognitive Load in AR-supported STEM Education

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Abstract: Augmented reality can create interactive and immersive STEM learning experiences. This study explored user experience and cognitive load using the Merge EDU platform, which employs a tangible Merge Cube to manipulate 3D objects. An exploratory study involved 13 middle school students and 11 STEM teachers performing AR-based tasks. Participants completed the NASA-TLX and UMUX questionnaires and participated in informal interviews. Results show that students experienced low TLX and high usability, while teachers reported higher workload and lower usability. A negative correlation between TLX and UX was observed for students, but not for teachers. Qualitative feedback indicated that students valued the interactive and exploratory aspects of the tool, whereas teachers focused on pedagogical integration and practical classroom use. The findings suggest that AR applications can effectively engage students and support learning with minimal cognitive effort, while teachers may benefit from additional training to optimize their experience.

Keywords: augmented reality, extended reality, Task Load Index, user experience

I. INTRODUCTION

Emerging technologies such as augmented reality (AR) have attracted increasing interest in educational research due to their capacity to create interactive and immersive learning environments. AR enables the overlay of digital information onto the physical environment, allowing users to explore and interact with complex learning concepts in an intuitive and engaging manner. This is especially useful in subjects where learners need to understand processes, structures, or systems that are not easily observed in the real world.

In recent years, a variety of AR applications and platforms have been developed to support STEM education by enabling visualization of abstract scientific concepts and facilitating experiential learning. These tools allow learners to interact with virtual models involved in chemical processes, physical systems, and biological structures in real time, thereby enhancing conceptual understanding and engagement. Also, the interactivity introduced by XR devices increases students engagement and encourage more active participation during lessons. As a result, AR-based learning environments have become increasingly integrated into STEM classroom activities and informal educational settings [1].

Despite the benefits of XR technologies for enhancing the learning process, their use in education also involves important trade-offs. One of the main challenges is the cost of XR devices. However, in recent years, XR technologies based on mobile devices have become more popular and offer

a good balance between the benefits of XR and the limitations of more complex and expensive hardware.

A promising tool used in AR and VR-based STEM educational activities is the immersive learning platform Merge EDU (<https://mergeedu.com>). This platform uses a physical cube (Merge Cube) whose faces contain graphical patterns that can be recognized by a mobile device camera. Once recognized, the application overlays three-dimensional virtual objects onto the cube, enabling users to explore and manipulate various 3D models through direct interaction.

Despite the growing popularity of this technology, only a limited number of studies [2] have investigated user experience (UX) and Task Load Index (TLX) associated with the use of Merge EDU in educational contexts. Understanding these aspects is essential for evaluating whether such technologies effectively contribute to improving the learning process.

In this paper, we present the results of a user study conducted to evaluate UX and TLX during interaction with AR-based activities offered by the Merge EDU platform. The study involved two groups of participants, students and teachers, in order to capture perspectives from both learners and educators, and to better understand how such technologies impact the learning process and to identify possible differences in experience.

In addition, the study examined the degree of acceptance of XR technologies and the level of interest among students and teachers in integrating such technologies into the teaching and learning process. The results obtained will be taken into account in the design and development of future XR applications as educational solutions tailored to the real needs of students and teaching staff.

The main contributions of this study are:

- (1) A comparative analysis of TLX and UX between students and teachers in AR-supported STEM learning;
- (2) An empirical investigation of the relationship between UX and TLX across these two groups of users;
- (3) Practical implications for the design and implementation of XR-based educational tools.

To guide this study, the following research questions were formulated:

RQ1: What are the differences in TLX between students and teachers when using AR tools?

RQ2: How does UX differ between these user groups?

RQ3: What is the relationship between TLX and UX for each group?

II. RELATED WORK

The integration of AR in educational contexts has been extensively investigated in recent years, particularly in STEM education [2]-[4]. AR technologies enable the visualization of abstract concepts in an interactive and immersive manner, which positively enhance learning outcomes [5] and enhance student motivation [6], [7]. For example, Bursztyn et al. [6] found in a study with university students that their interest in geoscience increased as they used more modules from a mobile field trip game based on geospatial tasks. This suggests that interactive and place-based AR activities can support student interest in the subject. In the study of DC circuit basics, Restivo et al. [7] examined how users learn with an AR application and showed that the application supported learning, increased user satisfaction, and led to very positive student views on the learning process and results.

Prior research highlights both the potential of AR technologies and their challenges in education, including issues related to the difficulty of operating AR applications for novice users and cognitive processing [3], [4]. Yet, students' comfort with an application is considered a critical factor influencing both learning outcomes and user engagement. According to Nielsen [8], systems should be intuitive, efficient, and minimize user frustration. Liu and Liu [9] showed that using mixed reality tools for knowledge visualization during STEM lessons had a significant impact on student learning progress. At the same time, the cognitive load required to use these applications should remain low, so it does not distract from the main lesson.

In this context, a growing body of research has examined the cognitive workload of AR applications in educational settings [10]-[12]. For example, Dunleavy and Dede [13] reported that well-designed AR visualizations can support learning without imposing additional cognitive demands compared to traditional instructional materials, demonstrating that AR does not inherently increase cognitive load when appropriately integrated into the lesson. Lee [1] examined the use of AR tools in an elementary school natural science course and found that these tools improved learning outcomes and reduced cognitive load compared to standard multimedia materials. Similar findings were reported by Thees et al. [14], who used AR glasses during physics laboratory activities. In contrast to some studies on student performance, no significant improvement in performance or understanding was observed. However, the study did show a significant reduction in the cognitive effort required to complete practical tasks when using AR glasses instead of traditional methods.

Differences in reported learning outcomes suggest that the effectiveness of AR have mixed effects and may depend on how these environments are implemented and experienced by learners [15], [16]. On the one hand, AR can reduce TLX by providing intuitive visualizations and contextualized information, for instance Küçük et al. [11] have shown that AR-based learning can enhance performance while maintaining manageable levels of cognitive demand. On the other hand, AR applications may increase TLX in certain situations, especially due to technical issues. For example, Altmeyer et al. [16] pointed out that some AR devices have a limited field of view and not all virtual information can be displayed. This limitation may reduce the positive effects of AR on student performance and preferences. They also reported that younger children sometimes struggle to adjust mobile devices to keep the virtual content visible, which might act as a distraction rather than an educational support.

Simon-Liedtke and Baraas [17] suggest that XR technologies can improve learning outcomes, but they also highlight several challenges. In addition to technical issues, they note concerns related to teaching approaches and the lack of widely accepted methods for using XR effectively in education. These results suggest that AR can support learning while maintaining or even lowering cognitive load, especially when the technology is well designed and appropriately used in the learning context. Thus, aspects related to usability and overall user experience are closely linked to cognitive load and may influence how effectively AR supports learning.

Higher UX is generally associated with lower TLX, as more intuitive systems reduce the mental effort required to complete a task, while UX also impacts the user's perception, efficiency, satisfaction and overall performance when interacting with technology [8], [12]. In educational contexts, this relationship between UX and TLX is particularly relevant, as excessive TLX can negatively affect learning outcomes [18]. It has been found that AR-based instructional systems can improve both UX and learning performance, although the effects depend on system design and learner characteristics [19]. For instance, in their case study, Young et al. [20] examined the integration of social virtual reality in a remote higher education STEM classroom and found that traditional learning tools and virtual tools led to similar student performance results, yet, systems that used embodied avatars helped students to reduce the sense of social isolation often experienced in remote learning. These findings suggest that AR tools have potential to reduce cognitive load and improve engagement, still further studies are needed to better evaluate the relationship between cognitive load and user experience, and how one may impact the other.

It has been found that AR-based instructional systems can improve both UX and learning performance [21]. As previous studies have shown, learners enjoy the learning process more when they engage with AR applications while also developing a better understanding of abstract concepts they engaged during lessons. However, most existing studies focus on a single group of users, who usually are students. This creates a limited understanding of how these systems function in real educational environments. Teachers are also an important part of this process, yet their experiences with AR tools are often overlooked. If teachers find these systems difficult to use or to integrate into their lessons, the overall effectiveness of such tools can significantly decrease. Few studies explored teachers experience with AR tools. For example, Piedade and Batista [22], in a study involving teachers who employed AR tools, reported a positive impact on the learning process, yet this impact was more evident when teachers received proper training. This suggests the need for studies involving more groups of participants involved in the learning process. Another important issue is that many studies evaluate either user experience or task load separately, despite results indicating that user experience can influence the cognitive load of using such tools.

Therefore, there is a need for empirical studies that evaluate UX and TLX across different user groups in AR-assisted educational environments. The present study describes a quantitative analysis of UX and TLX in a STEM learning context based on AR, with a particular emphasis on differences between students and teachers. In addition, this study aims to provide an understanding of how these two groups experience the same technology.

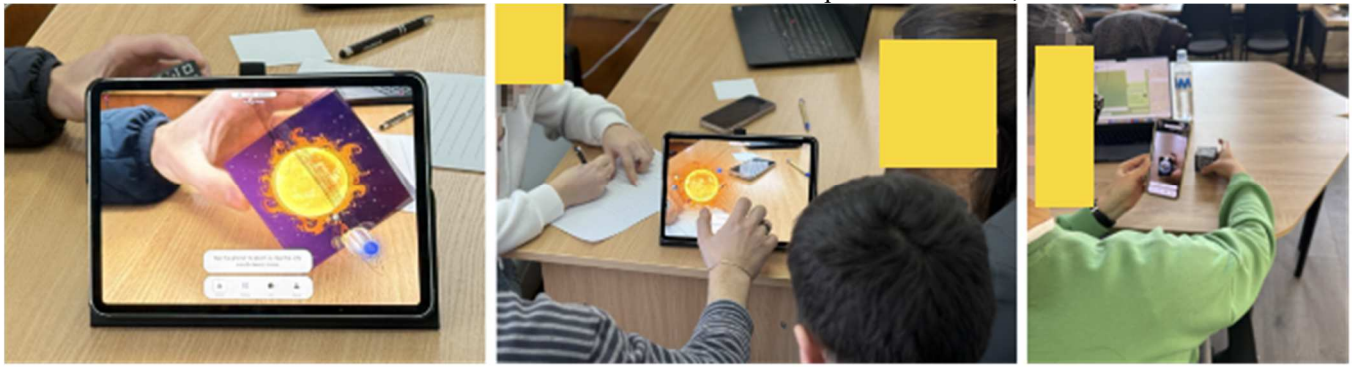


Fig. 1. Experimental setup: the AR app (left), participants during training (middle), one participant during the interaction part (right).

III. STUDY

We conducted a user study to evaluate the workload and overall user experience of participants during the STEM learning process when using an AR tool to visualize concepts, with a particular focus on the relationship between UX and TLX. The study involved two groups of participants: middle school students and STEM teachers, in order to capture both learner and educator perspectives.

A. Participants

We recruited 13 middle school students aged between 15 and 17 years ($M = 15.8$), including 5 male and 8 female participants. Also, 11 STEM teachers (2 male and 9 female) participated in the study. Their teaching experience ranged from 24 to 50 years ($M = 35.8$). The teachers specialized in different subjects, including physics, biology, mathematics, and computer science, which provided a broad perspective on the educational use of the AR tool. As an exploratory study, the sample size is appropriate to reveal general trends and allow a comparison between the two participant groups, and this range of sample size is commonly used in the scientific literature [22]. All participants took part voluntarily. They were informed about the purpose of the study and the procedure before starting. They were also assured that their data would remain anonymous and that they could withdraw at any time without any negative consequences.

B. Procedure

During the study, participants used a tablet (Apple iPad Pro) with a physical Merge Cube (Fig. 1). This setup allowed them to visualize and interact with 3D virtual objects in an augmented reality environment. The application included interactive visualizations for several STEM subjects, including physics, biology, mathematics, and computer science.

Before the task, participants were involved in a short training session. During this session, they were shown how to use the application, how to handle the Merge Cube, and how to visualize and interact with the virtual objects. Participants were given time to test the system and ask questions to ensure they understood how it worked.

After the training session, participants were asked to complete several tasks related to STEM subjects. Each task required participants to explore a virtual object or concept using the AR tool and to identify qualitative or quantitative information, or to describe specific features. For example, one task asked participants to explore a 3D model of the solar system, list the planets observed on it, calculate the distance

from each planet to the Sun, as well as the diameter of the

Earth (Fig. 1, left). Another task asked participants to examine the components of a computer and describe them. Participants were given a set of tasks of comparable difficulty selected from various STEM subjects familiar to them. All participants completed the same set of tasks, without time limits and under similar conditions to ensure consistency of the experimental procedure. Participants spent on average 20 minutes interacting with the application during this stage.

C. Measurements

The overall structure of the study is illustrated in Fig. 2. After completing the tasks, participants were asked to fill out a questionnaire to evaluate cognitive workload and user experience. The questionnaire included the following measures:

NASA-TLX. We evaluated users' cognitive load using the NASA Task Load Index (NASA-TLX) questionnaire [24]. This is a widely used tool that measures perceived workload across six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each dimension is rated on a scale from 0 to 100 with flexible steps, or sometimes on a smaller custom scale (commonly 1 to 20 or 1 to 10). Because our study involved school students, we used the simpler 1 to 10 scale, which is a format they are already used to in school grading, making it easier for our child participants to understand and use, and which is consistent and allowed in the NASA-TLX procedure. To compute the final NASA-TLX score, we first rescaled all responses from the 1 to 10 range to a 0 to 100 scale and calculated the overall workload score by combining the six dimensions. The final score ranges from 0 (low mental workload) to 100 (high mental workload).

UMUX. We evaluated users' perceived usability using the Usability Metric for User Experience (UMUX). This is a short and reliable tool that measures overall system usability using four questions rated on a 7-point Likert scale [25], from 1 (strongly disagree) to 7 (strongly agree). We slightly adapted the wording of the items, keeping their original meaning, to make sure all participants clearly understood them, especially the student group. To calculate the final UMUX score, we followed the standard scoring procedure: the scores of negatively connoted items were reversed, and all the responses were then converted to a UMUX score ranging from 0 to 100 strictly following the recommended UMUX scoring rules [25].

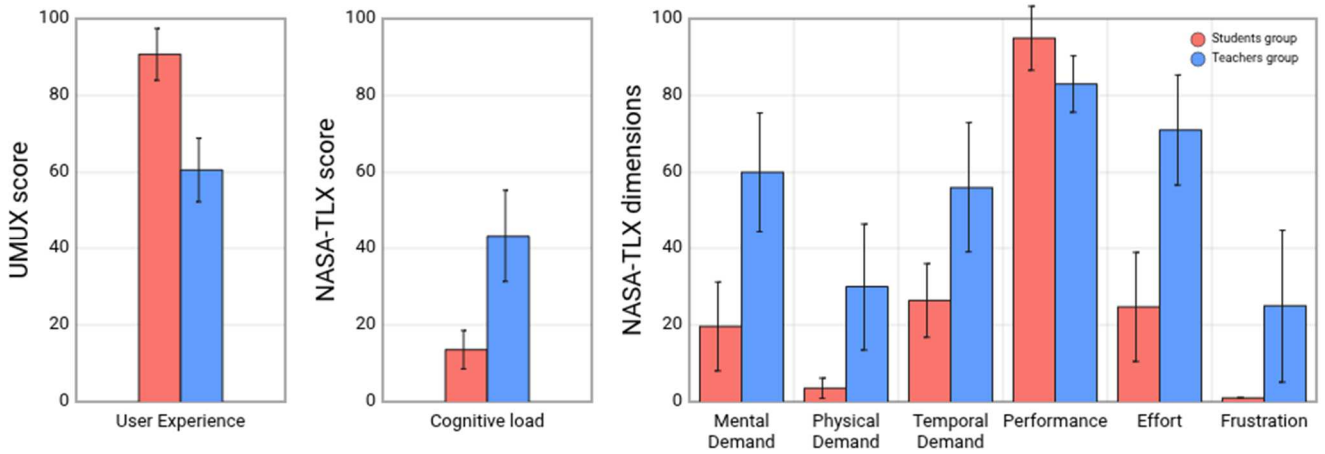


Fig. 2. Average scores for perceived User Experience (left), cognitive load (middle), and cognitive load dimensions (right).

After completing the questionnaire, participants took part in a short informal interview. During this session, they were encouraged to share their opinions about the AR tool, what they liked, what they found challenging, and how the tool supported them to perform the task. They were also asked how they felt while using the application, what aspects they liked the most, what they found difficult or frustrating, and whether they encountered any problems during its use. In addition, participants were asked to describe their overall experience (e.g., easy, difficult, interesting, or engaging) and whether they believed the application helped them better understand the task or concept.

Teachers were also asked about how such an AR tool could be used in real classroom settings. They discussed possible benefits for explaining abstract concepts during lessons as well as potential challenges. Furthermore, they were asked to suggest ways in which the application could be improved, as well as whether they would be willing to use it again in the future and under what conditions.

IV. RESULTS

The results of our study show that XR technologies had a generally low workload for students when performing some tasks in the context of STEM education. The average NASA-TLX score for the student group was 13.6 on a scale from 1 to 100 ($SD = 9.2$). Regarding the individual dimensions, temporal demand, effort, and mental demand had the highest scores, with values of 26.4 ($SD = 17.6$), 24.7 ($SD = 26.1$), and 19.6 ($SD = 21.2$).

In contrast, frustration and physical demand had the lowest scores, with values of 1.0 ($SD = 0$) and 3.5 ($SD = 4.8$), which shows lower workload in these areas.

The teacher group reported a higher workload, with an average NASA-TLX score of 43.3 ($SD = 20.3$). The highest scores were for effort, with an average of 71.0 ($SD = 24.2$), followed by mental demand with 60.0 ($SD = 26.2$) and temporal demand with 56.0 ($SD = 28.7$). Teachers also reported higher scores than students for frustration and physical demand, with averages of 25.0 ($SD = 33.7$) and 30.0 ($SD = 27.9$). Since the data did not meet the assumption of equal variance (Levene's test showed $p = 0.038$), we used Welch's t -test to see the difference between the two groups. The results showed a significant difference between students and teachers' groups, $t(22) = -4.49$, $p < 0.001$, which indicates that teachers experienced a higher workload than students.

In terms of user experience, measured with the UMUX scale, students gave positive feedback. The average UMUX score for students was 90.7 out of 100 ($SD = 12.4$), which shows good usability. Teachers gave lower scores, with an average of 60.6 ($SD = 14.0$), which suggests that they had more difficulties than students.

Welch's t -test showed a significant difference between the two groups, $t(22) = 5.53$, $p < 0.001$.

Pearson correlation analysis showed a negative correlation between NASA-TLX and UMUX scores for the student group ($r = -0.622$, $p = 0.023$), which means that higher workload was related to lower usability.

For the teacher group, no significant correlation was found ($r = -0.139$, $p = 0.684$).

Unlike previous studies that focus on a single user group, this study provides a comparative perspective between students and teachers, while also examining the relationship between cognitive load and user experience within the same experimental framework.

V. DISCUSSION AND LIMITATIONS

The results show a clear difference between students and teachers when using XR technology, represented in our study by a configuration involving a mobile device and visual feedback, two dimensions highlighted in [26]. Students reported very low workload and very high user experience, which suggests that they found the system easy to use and not mentally demanding. In contrast, teachers reported much higher workload and lower usability scores. This shows that the same system was experienced very differently by the two groups. The relationship between cognitive load and user experience across the two groups is illustrated in Fig. 3. The difference may be due to the differences in the level of familiarity with XR technologies. Students seem to be more willing and able to adapt quickly to new technologies, especially those with a high level of interactivity, while teachers may need more time to learn how to use them. Additionally, the large level of standard deviation within teachers' groups suggests that there is not a strong consensus regarding the level of workload required to use XR technologies through smartphones.

The results also show that for students, higher workload is strongly correlated to lower usability. The students perceive the XR interaction as more demanding, when the experience is less positive. However, this relation was not found for teachers. The teachers' group seems to evaluate the usability based on other criteria, such as the usefulness of the

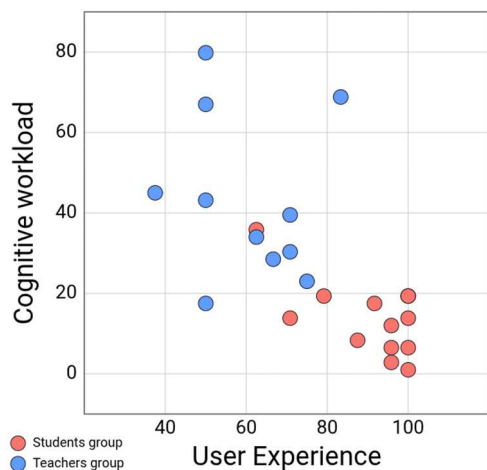


Fig. 3. Relationship between cognitive load and user experience across students and teachers.

system for teaching, rather than only on how easy it is to use, or other criteria.

The informal interview revealed that the students group evaluated the experience with the application with focus on the interactive aspects of the application. They described it as engaging and useful, especially for visualising objects during the task. For instance, several students mentioned that being able to view objects in 3D and from different angles helped them better understand abstract concepts and made them feel more comfortable. Others pointed out that the application was easy to use, describing it as intuitive and smooth to interact with, which made the overall experience enjoyable.

Students also linked their positive experience to the low level of difficulty. Most of them reported no major issues while using the application, and any small difficulties were mainly related to getting used to it at the beginning or occasional technical problems. This suggests that the application is designed in a way that reduces effort and allows students to focus more on learning. In addition, interactivity was seen as an important part of the learning process. Students felt that combining real and virtual elements, along with interactive visualisations, helped them understand the content more clearly. All of them agreed that the application improved their understanding, especially through direct interaction with 3D models.

Finally, students showed a strong interest in using the application again, describing it as interesting, innovative, and helpful for learning. This supports the idea that XR applications can increase engagement and motivation, making them useful tools in STEM education.

On the other hand, some teachers focused more on how the application could be used in their teaching practice. This may have increased their mental effort during the task. For instance, one participant from the teachers' group mentioned that the activity required additional time to understand the setup and organize the class, noting that it "took time to understand how the application works and to set up the task properly", suggesting that they were thinking more about how to integrate it into their lessons. While another participant pointed out that "it would be useful if the application had more explanations or guidance for users", highlighting the need for clearer instructional support when applying the tool in a teaching context. For example, Upadhyay et al. [27] showed that teachers are often not ready to use XR technologies in class, as they may lack experience

or knowledge about how to use them as teaching tools and there is a need for educators training among other limitations.

Despite the differences in workload and user experience, participants from both groups said during the interviews that they would like to use XR technologies in the future, either for learning, as students, or as teaching tools. The findings suggest that XR technologies can be effective and easy to use for students in STEM education. However, teachers may need more support, training, and guidance to reduce their workload and improve their experience.

There are several limitations in our experimental design that should be considered when interpreting the results. First, the study involved a relatively small number of participants and was conducted in a controlled environment. This setup makes it easier to manage variables, but it may not reflect the complexity of real classroom situations, where various external factors can influence outcomes. Participants were recruited from only a few schools, which limits the diversity of the sample. Their previous experience with immersive technologies may also have affected how easy they found the system to use and how much mental effort they reported. For example, participants who are already familiar with such tools might adapt more quickly and report lower cognitive load than those with no prior exposure, which was observed in previous studies as well [22].

Second, the results may have been influenced by a novelty effect. Because the technology was relatively new for our participants, they may show higher interest and motivation at the beginning, which does not always last over time. To better understand how students and teachers interact with these tools in the long term, future studies should examine their use over longer periods, such as several days or weeks, and across different learning sessions.

VI. CONCLUSION

We examined the correlation between UX and perceived workload when using AR applications that allow visualising and manipulating virtual objects through a physical proxy, across two groups: school students and STEM teachers. Our study shows that this type of AR tool is suitable for students in terms of both perceived workload and user experience. The results show that the more students enjoy using the tool, the less effort they feel is needed to understand the topic or finish a task. This suggests that such tools that support learning through visualisation can help students stay engaged with minimal cognitive effort. However, teachers report a different experience. For them, these tools can feel more difficult and demanding. They may need additional time to understand how the system works and how to integrate it into their lessons. These findings contribute to a better understanding of how different user groups interact with AR technologies and provide guidance for improving the design and implementation of XR-based educational tools.

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