



Studying the User Experience of an Educational AR-Based App for Smart Glasses

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Abstract. The steady evolution of wearable technology—along with augmented reality (AR)—has enabled important advances in teaching and learning. We present *STEM Education*, an interactive AR application for smart glasses. We evaluate the app’s user experience (UX) with undergraduate STEM (Science, Technology, Engineering, and Mathematics) students. More specifically, we focus on the students’ overall satisfaction, degree of technological acceptance, mental workload, and emotional response. Our observations suggest that the app improves the student’s learning quality, while promoting high levels of engagement and satisfaction. We discuss these findings and their implications in the design of similar technology for educational contexts.

Keywords: HCI · UX · Usability · AR app · Smart glasses · STEM areas

1 Introduction

The use of AR-based tools with smart glasses has enabled a myriad of applications in educational settings and industry training [1]. AR facilitates the visualisation of complex and abstract concepts, increasing students’ interest and concentration through deep conceptual understanding and self-learning [2]. It also has potential to create personalised environments, offering unique immersive experiences and increasing acceptance [3]. For these reasons, AR research has become a central topic in HCI, an area in which several types of experimental instruments are used to assess the UX of AR-based tools [4]. The ISO/IEC 25010 standard defines usability as the “*degree to which a product or system can*

be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." [5]. UX evaluation is relevant in HCI, mainly when there are new artefact contributions [6] as it makes possible to characterize the quality of a product and/or service by referring to the users' perception, emotions, and cognitive responses [7]. The emotional aspects are often assessed through a variety of approaches (e.g., questionnaires, interviews, video analysis [8]).

In this paper, we study UX-related aspects reported by STEM students' after using an AR-based app for smart glasses that supports learning of STEM concepts. More specifically, we aim to provide a holistic description of the students' experience with the app by answering the following research questions:

- RQ1:** What is the degree of satisfaction of students after using AR app?
RQ2: What is the degree of technological acceptance students report?
RQ3: To which extent does the AR app influence the perceived workload?
RQ4: What emotions do students exhibit after the experiment?

Our study expands previous research in this area, uncovering how the app's support is perceived by students when they interact with smart glasses in an educational environment. Our observations can inform further deployments of AR-based tools and related technology in educational settings.

2 Related Work

In recent years, wearable technology has developed rapidly. Allegedly, smart glasses are the most widely used wearable technology in educational settings. This has led to a myriad of apps that can be used in the classroom [9]. Saidin et al. [10] state that AR has the potential to support teaching and learning processes because it is dynamic, successful, and relevant. Thus, smart glasses can create new experiences for students through immersive environments, enhancing perception, interaction, engagement, and cognition. For example, AR can enable students to conduct lab experiments virtually [11]. Along these lines, Akçayır et al. [12] show that the integration of AR-based components can improve science students' learning abilities and laboratory skills. Also, Alshaikhi et al. [13] mention that AR can help to visualize events that are otherwise impossible to see in real laboratory environments, making a significant impact on the learners' experience. Google Glasses have been used in medicine to support medical education and training [14]. Similarly, Kocajko et al. [15] studied the use of eGlasses to measure and process vital signs, to perform multisensory measurements, as well as to estimate blood pressure and heart rate.

We build upon the work referred in the preceding paragraphs by evaluating UX-related aspects of a smart glasses AR-based app for STEM education. Our research is motivated by the previous findings of Santana et al. that highlight the lack of augmented reality apps for the four STEM areas and the lack of understanding on the limitations of smart glasses when used in this field of education [1].

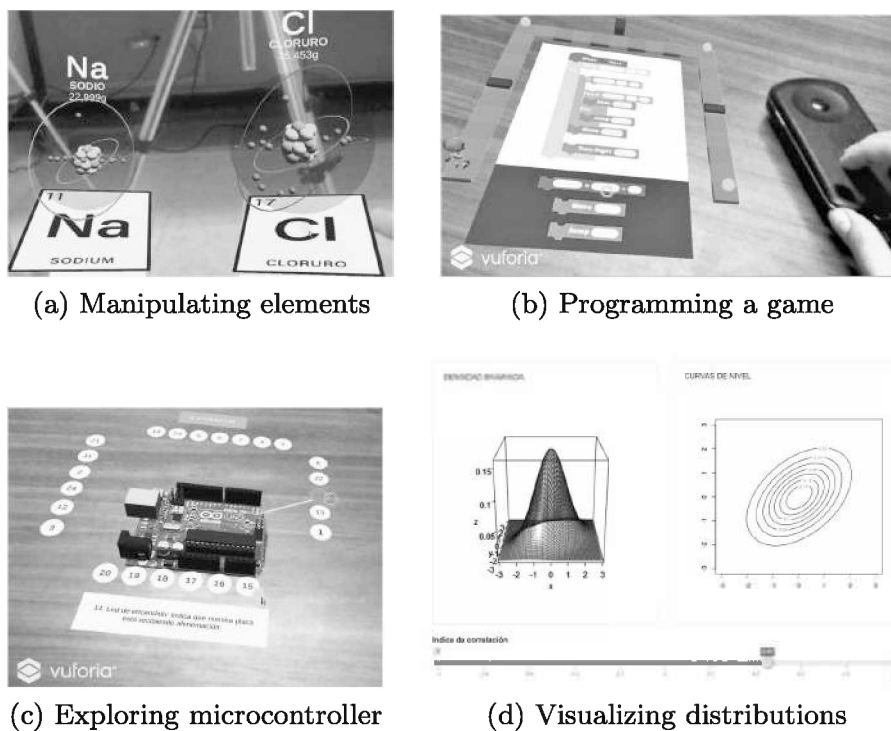


Fig. 1. Using STEM Education app scenes on smart glasses

3 The *STEM Education* app

We designed the *STEM education* app to support learning concepts and activities, while also promoting a unique user experience. The app addresses key themes of the four areas of STEM education. More specifically, the version of the app we used in this study allowed the interactive exploration of the following concepts:

- **Science: Manipulation of elements of the periodic table.** Using AR markers, students can join atoms of the chemical elements depicted on the smart glasses. When appropriate, these interactions lead to chemical reactions that are animated on the device's screen (Fig. 1a).
- **Technology: Visual programming of a game.** An incomplete, block-based visual program is depicted at the beginning of the activity. Using the smart glasses' trackpad, students must complete the program, which makes a robot move through a predefined path (Fig. 1b).
- **Engineering: Interactive exploration of a microcontroller.** AR markers located on a physical Arduino board are detected by the glasses' camera. In response to this, the device superimposes relevant annotations to support understanding of the Arduino board's components. (Fig. 1c).
- **Mathematics: Visualization of statistical distributions.** Distributions are depicted through the glasses' web browser. Students control the distributions' parameters through interactive widgets (e.g., sliders) (Fig. 1d).

We deployed and tested the *STEM education* app with the Epson Moverio BT-300 smart glasses.¹ The app was implemented with Unity² and Vuforia,³ two SDK for building AR apps. We used the open source version of these pieces of software, as they enable the development of non-commercial apps with research-oriented and educational purposes.

4 Experimental Design

This section explains the experimental protocol followed to evaluate the app.

4.1 Participants

We recruited 24 undergraduate STEM students (12 males and 12 females) between 19–22 years old ($\mu = 20$, $\sigma = 1.04$). They were enrolled at a local university in several programs: chemical engineering, computer science, statistics, and mechatronics. Prior to the execution of the study, three of them were completely unaware of AR and VR concepts.

4.2 Apparatus

We addressed our research questions with the Epson Moverio BT-300 smart glasses (Fig. 2a). This device's display has a binocular see-through viewing and supports projection of 3D content (resolution of 1280×720 pixels). It has a camera with ambient light and motion sensors and include a wired external controller (Fig. 2b) that enables tangible user input through a touchpad with buttons to navigate around what is projected in front of the user's eyes.

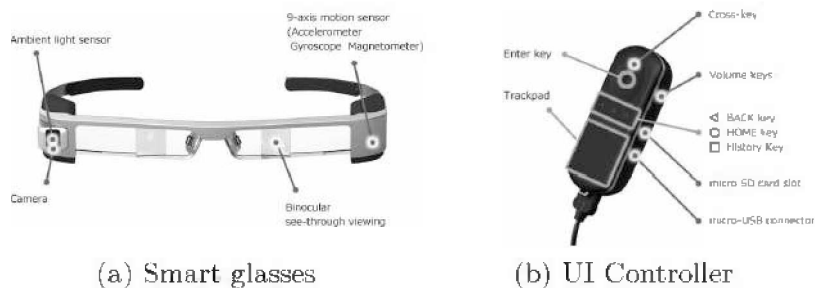


Fig. 2. Epson Moverio BT-300 smart glasses and UI controller

¹ <https://moverio.epson.com>.

² <https://unity.com>.

³ <https://developer.vuforia.com>.

4.3 Procedure

We focused on getting participants' impressions on the *STEM education* app. After signing the consent form and filling out the demographic questionnaire, each participant was given a printed instruction sheet on how to use the app, and we provided an explanation on the activities to be performed.

Participants then proceeded to interact with the smart glasses to complete four activities: In the first activity, they had to use the **Science** component of the app. Participants were provided with six AR markers to visualize and manipulate the available chemical elements. Participants made several combinations with the AR markers to visualize the creation chemical reactions. The second activity involved the use of the **Technology** app component. They scanned a given AR marker and, using the glasses' trackpad, finished the block program provided to move the robot of the game. In the third activity, they used the **Engineering** part. Each participant was given a physical Arduino board and placed it in front of the smart glasses. They then used the trackpad to deconstruct the board and analyze each component separately. In the last activity, participants used the **Mathematics** component. A frequency and a bivariate normal distribution were shown in a web page. Using the device's trackpad, participants were able to modify the parameters used to generate each distribution and observe the effects of their interactions.

Participants spent about 15 min to complete the activities with the app. They then filled out four closing questionnaires and shared their experiences, preferences and emotions on the app in a semi-structured interview.

4.4 Data Collection

We used questionnaires to collect participants' perceived: a) usability, b) technological acceptance, c) overall experience, and d) emotions. To this end, we adapted four standardized questionnaires: a) the **Post-Study System Usability Questionnaire (PSSUQ)** that measures usability through three dimensions: system usefulness, information quality, and interface quality; b) the **Unified Theory of Acceptance and Use of Technology (UTAUT)** questionnaire, that measures technological acceptance through six dimensions: performance expectation, effort expectation, social influence, facilitation condition, behavioral intention, and attitude; c) the **Nasa Task Load Index (NASA-TLX)** questionnaire, that assesses the user's experience through six dimensions: mental demand, physical demand, temporal demand, performance, effort, and frustration; and d) an **Emotions Questionnaire**, that measures people's emotional response focusing on the six basic emotions proposed by Ekman [16].

We modified some of the statements of these questionnaires to fit the purposes of our study. For example, we removed the statement "*The device gave error messages that clearly indicated how to solve the problem*" from the PSSUQ because no error messages were displayed during our experiment.

5 Results

In this section we first discuss the quantitative analysis of the questionnaire data we collected. This is followed by the qualitative analysis of the interviews.

5.1 Quantitative Analysis

On a likert scale [1 – 7], the average ratings across all participants for the dimensions of the **PSSUQ** questionnaire were: 6.00 for the *System usefulness*, 6.00 for the *Information quality*, and 6.38 for the *Interface quality* (Fig. 3a). The overall score was 6.13. The participants' ratings for this questionnaire show that the usability of the app was affected mainly by the *information quality* participants perceived. The average across all participants for the dimensions of the **NASA-TLX** questionnaire are depicted in (Fig. 3b). In the range [1 – 20], the *Physical demand* was the least perceived workload, with a score of 4.00. This was followed by *Performance* (6.50) and *Frustration* (7.50). Both *Mental* and *Temporal demand* were rated at 8.00, and *Effort* reached the highest score (10.50). We applied the Shapiro-Wilk test to the data of this questionnaire and did not find statistical evidence that the observations were not normal ($W = 0.97$, $p = 0.55$). Our data indicates that 38% of the mental workload corresponds to a low, 58% to medium, and 4% to a high level of mental workload. The overall result of the NASA-TLX questionnaire suggests that participants experienced a medium level of workload. Their ratings for the **UTAUT** questionnaire (Fig. 3c) were collected using a [1 – 7] Likert scale. The lowest average scores correspond to *Facilitation condition* (5.33). The remaining dimensions were rated with higher scores: *Effort expectation* (6.00), *Behavioural intention* (6.00), *Performance expectation* (6.50), *Attitude* (6.75) and *Social influence* (6.83). The average scores for the participants' emotional responses are shown in (Fig. 3d). The six **Emotions** of the questionnaire, rated with a [1 – 7] scale, were divided into two groups. Negative emotions received low scores: *Anger* (1.00), *Fear* (1.00), *Dislike* (1.00) and *Sadness* (1.00). On the other hand, positive emotions received high average scores across all participants: *Joy* (6.00) and *Surprise* (5.00). In general, these results suggest that STEM education app induce a mostly positive emotional response in the participants.

We also analyzed the internal consistency (or reliability) of each questionnaire's items through the Cronbach's alpha [17]. This coefficient measures how closely related a set of items are in multiple-question Likert scale surveys. The results of the reliability test were as follows: 0.85 for the PSSUQ, 0.84 for the NASA-TLX, and 0.97 for the UTAUT questionnaire. The Emotions instrument received a reliability score of 0.36. The reliability coefficients of the constructs (i.e., greater than 0.7) suggest that the questionnaire items have high internal consistency. In our study, this is true for the PSSUQ, NASA-TLX and UTAUT questionnaires.

Finally, we conducted a principal component analysis (PCA) to identify strongly related correlations between the dimensions of the applied instruments. We used this method to measure the variability of the data and to determine the

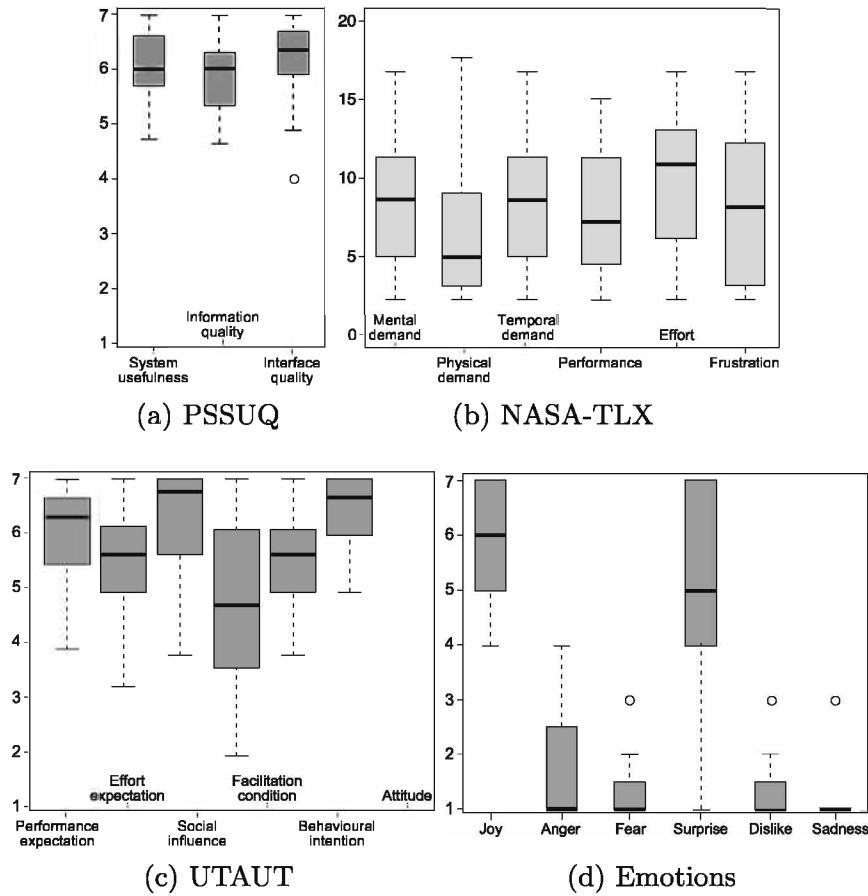


Fig. 3. Participants' average ratings for the questionnaires' dimensions

appropriate number of clusters. The principal components (PCs) resulting from the dimensions of the **PSSUQ** and **UTAUT** questionnaires explain 74.74% of the total variance of the usability and technology acceptance data (Fig. 4a). Two clusters emerge from this analysis: C1 (*System usefulness, Information quality, and Interface quality*) and C2 (*Facilitation condition, Social influence, Performance expectation, Attitude, Effort expectation and Behavioural intention*). The dimensions of both clusters have a strong positive correlation. The PCs of the **PSSUQ** & **NASA-TLX** questionnaires explain 66.79% of the total variance. This data refers to usability of the app and the participants' perceived workload (Fig. 4b). These components lead to three clusters: C1 (*Mental, Temporal, and Physical demand*), C2 (*Information quality, Interface quality, and System usefulness*), and C3 (*Effort, Performance, and Frustration*). The dimensions of C1 and C2 have a strong positive correlation, while those of C3 have a strong negative correlation. These results suggest that participants had problems performing certain activities with the app, resulting in a negative experience. The PCs that result from the **NASA-TLX** & the **Emotions** questionnaires data explain 58.22% of the total variance (Fig. 4c). This data refers to participants' perceived workload and their emotions. Two clusters emerge: C1 (*Joy, Surprise, Temporal,*

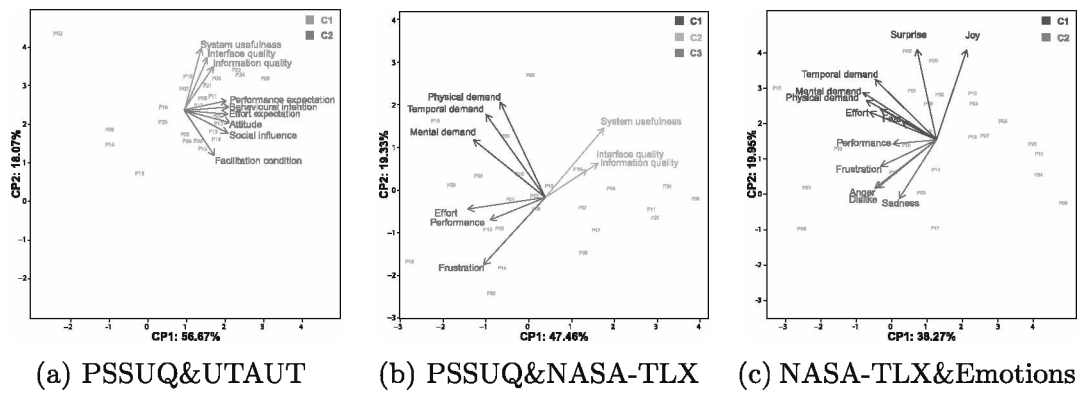


Fig. 4. Clusters emerging from our PCA. Participants' IDs appear in gray.

Mental, Physical demand, Effort, and Fear) and C2 (*Performance, Frustration, Anger, Dislike and Sadness*). This data reveals that, while performing the activities with the app, participants had a positive emotional response with a medium mental workload.

5.2 Qualitative Analysis

The participants comments' support our quantitative results. Students had good experiences and positive attitudes toward the app: *"I liked it a lot."* [P03, P11]; *"It was quite entertaining, I enjoyed seeing how atoms come together to form compounds."* [P17]; *"The experience was good."* [P18, P23].

They also made comments on the different components of the app:

Science: *"You could see how the atoms come together to form reactions."* [P17]; *"I found it very dynamic. One thing is to read the books and another is to see how elements join and form bonds. This should be integrated in our education."* [P23].

Technology: *"Very interesting to see how I can program the robot so that it moves does what I tell it to do."* [P04]; *"It was very cool to do programming with blocks."* [P07]; *"I was able to assemble bit by bit and make the robot move."* [P13]; *"I really liked the robot, because it is a game where you learn and play."* [P23].

Engineering: *"The circuit showed everything in detail. It was incredible!"* [P01]; *"I found it very interactive, it was a very interesting experience."* [P05]; *"I have been willing to see something like this for a long time."* [P06].

Mathematics: *"It teaches you to see how a bivariate distribution and a correlation distribution behave."* [P04]; *"I liked seeing the statistical graphs in 3D."* [P13]; *"This makes easier to understand what the frequencies consist of and what happens when they change in real time."* [P24].

Regarding their learning experience, most participants enjoyed using the app, as illustrated in these exemplary statements: *"If this application is used to teach people, it would be very didactic. It is very easy to use, and it is well done."* [P09];

“It was very interesting indeed. It was something that draws a lot of attention like saying ‘wow’ and learning at the same time.” [P20]; “It is a good tool for absolutely all areas.” [P24].

6 Conclusion and Future Work

This paper evaluated the *STEM education* app, which supports learning of STEM concepts. Our study focused on four UX-related aspects: usability, technology acceptance, mental workload and emotions. Students had a good overall experience with the app, which suggests its potential to be applied in real educational settings at the university level.

The results from the **PSSUQ** suggests that participants were very satisfied when using the app (**RQ1**). The **PSSUQ** data positively influenced the **UTAUT** questionnaire data, indicating a good level of technological acceptance (**RQ2**), but also suggest that the app features associated with *Facilitation Condition* should be improved. Participants saw great potential in the use of the four STEM areas. Our results show a medium workload (**RQ3**) induced by the interaction with the app. The results of the **NASA-TLX** questionnaire are supported by previous research on the use of AR apps with smart glasses [18]. These quantitative outcomes are consistent with participant statements collected after the experiment. Most participants showed positive **emotions** after using the app (**RQ4**). Despite some comments about AR markers when objects were displayed too close when placed in front of the smart glasses and certain additional features that participants expected the app included, the scores associated to negative emotions (*anger, fear, dislike, and sadness*) were not significant. However, we also identified problematic interactions (e.g., the focus of the AR markers with the smart glasses) and issues related to the quality of information and features that the student expected from the app.

This study can guide HCI researchers to improve the user interface of AR-based tools for educational settings. Future work will consider experiments with more diverse groups of students, other types of devices, as well as longitudinal studies and more complex analyses. We will also aim at including more objective measurements of cognitive workload and emotions by using specialized headset devices. These investigations will enable us to build a more objective characterization of the user experience students undergo when interacting with the *STEM education* app.

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