A Study on User Experience of Smart Glasses for Higher Education Students

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Abstract — **This paper reports a study on the User experience (UX) of STEM (e.g., Science, Technology, Engineering, and Mathematics) students using smart glasses and an interactive Augmented Reality (AR) educational app. The results show that the AR app provides a good UX, despite the presence of some form factor issues. Students' usability ratings for both the AR app and the smart glasses, are positively correlated with the students' perceived learning. The results of this study can be used as a guideline to design and develop further immersive e-learning technologies.**

Keywords - Human-computer Interaction; Smart Glasses; Augmented Reality; User Experience; Usability; STEM Education.

I. Introduction

Augmented reality (AR) has three main characteristics: (i) it combines real and virtual objects, (ii) it enables real time interaction, and (iii) it has the potential to place the end-user in an immersive three dimensional environment [1]. AR apps introduce *augmented objects* into real world scenes that are often captured with a camera. This type of interaction can create new modes of learning and training, accessible even for students with low experience of digital devices [2].

Smart glasses are wearable devices that can superimpose information onto what a person sees at runtime. Together with AR, these devices offer great potential for educational settings. Thus, smart glasses and AR apps have gained popularity in recent years, and have become exceptional teaching assets in different levels and fields of education, and different educational settings. Their benefits include increased motivation and learning effectiveness [3]–[5] and a myriad of benefits for instructors [6], [7]. This type of technology promotes students' learning in interactive environments, fostering the development of new skills as well as increasing opportunities for analytical thinking and critical reflection. It is worth noting that smart glasses and AR applications are evolving, presenting new possibilities and challenges for the area of Human-Computer Interaction (HCI) research.

The ISO 9241 norm defines usability as the "*degree to which a product or system can be used by specific users to achieve specific objectives effectively, efficiently and satisfactorily in a given context of use*" [8, part 11]. Usability tests everything from aesthetics to compatibility, which helps to improve software quality [9]. User Experience (UX), on the other hand, is defined as the "*perceptions and responses of a person resulting from the use and/or anticipated use of a product, system or service*" [10]. Therefore, UX focuses on users' emotions, feelings and judgements about a system [11]. Analyzing UX is essential to increase user satisfaction and motivation.

We present a study that evaluates UX in an educational setting. More specifically, we focus on assessing the experience of Science, Technology, Engineering and Mathematics (STEM) students with smart glasses and an AR app designed to support specific learning tasks in these four knowledge areas. Our main goal is to understand how this technology supports STEM students in their learning process.

Our contribution is twofold: (i) we evaluate the UX and usability of smart glasses with STEM students and (ii) assess the effectiveness of an AR app that supports learning of the 4 STEM areas with undergraduate students.

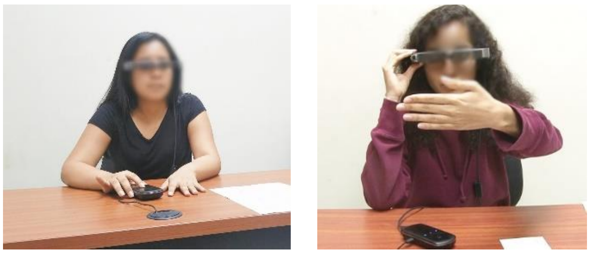
II. Related Work

Many studies have addressed the user experience of Augmented Reality (AR) applications using smart glasses. In this work, we focus on smart glasses using AR in a STEM educational setting.

Previous research efforts have identified UX as a key factor for the success of AR oriented to educational goals [5, 6]. We explore user experience in detail using different standardized questionnaires that measure UX and through semi-structured interviews. These observations can guide designers when working toward improving UX of similar technology.

A. Smart Glasses in Educational Settings

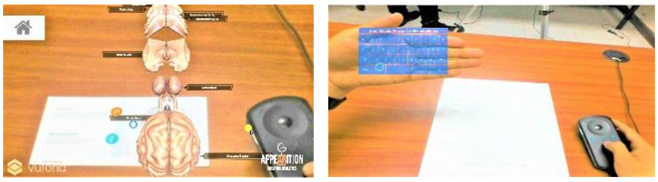
Smart glasses have been extensively used in educational settings (Figure 1). Silva et al. [13] presented *the Glassist*, an application for Google Glass that allows elementary school teachers to create individual portfolios for students [14]. At the high school level, Kuhn et al. [15] developed an application to perform physical experiments. These studies suggest that although this technology can bring several benefits into learning spaces, it can also increase the cognitive workload of the students.



(a) (b)

Figure 1. Participant in front of desk wearing smart glasses: (a) using Trackpad; (b) using gesture control

Many AR applications with educational purposes have been proposed both as marketed products as well as research prototypes. We study the use of two apps for the Epson Moverio smart glassses: **pARtum**[1] and **Augumenta Virtual Surface**[2] in Study 1 (Figure 2).



(a) (b)

Figure 2. Marketed apps: (a) pARtum ; (b)Augumenta Virtual Surface

Similarly, our research is motivated by the previous findings of Santana et al. on the lack of AR applications and studies on the limitations of the smart glasses in education [3]. For this reason, we created an authored app called *STEM Education* and we assess it in Study 2 (see Figure 3).

III. Objectives and Research Questions

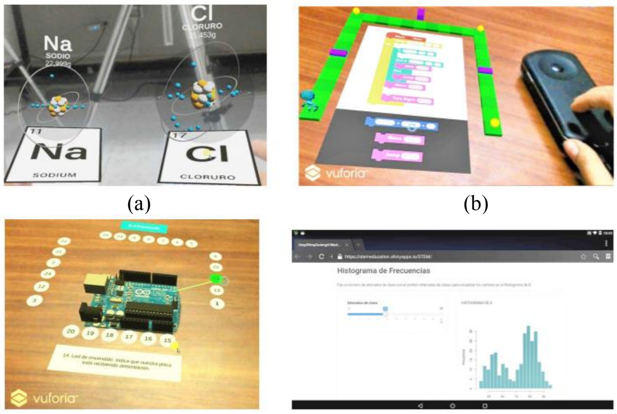
The aim of this research is twofold. First, we analyze the UX of STEM students using smart glasses. Second, we evaluate their experience using app especially developed to support learning of STEM concepts. We do this by investigating the following research questions (RQs):

RQ1: How satisfied are students after using the smart glasses and AR app for the first time?

RQ2: What is the degree of technological acceptance reported by the students?

RQ3: To which extent do the smart glasses and the AR app influence the students' perceived workload?

RQ4: What feelings do students report after their experience with the smart glasses and the AR app?



(a) (b)

(c) (d)

Figure 3. STEM education app: (a) Science; (b) Technology; (c) Engineering; (d) Mathematics

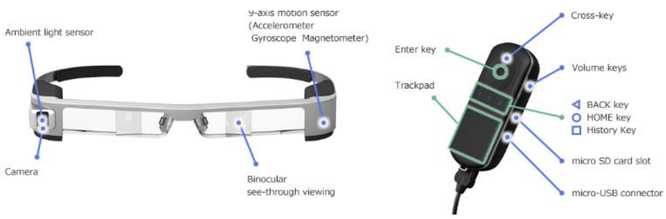
IV. Methodology

A. Participants

A total of 24 participants aged 19-22 years old (M=20, SD=1.04), 12 males and 12 females, participated in the experiment. The participants were undergraduate STEM students in: Chemical engineering, Computer Science, Mechatronics, and Statistics.

B. Experimental Setup

The experiment was conducted using an Epson Moverio BT-300 smart glasses that includes a wired external controller (Figure 4), enclosing the device's battery and processor. In addition, we used 2 marketed apps (pARtum & Augumenta Virtual Surface) and an application developed by the authors focusing on the four STEM areas. During the study session, the glasses were connected to a laptop through a wireless connection to record the participants' actions. We used AirDroid Web to remotely control what the users saw through the smart glasses. An external camera recorded participants' movements and behaviors. We analyzed this data to interpret the student's subjective experiences with the devices.



[1] https://www.appearition.com

[2] http://augumenta.com

Figure 4. Epson Moverio BT-300 smart glasses and Controller

C. *Experimental Design and Procedure*

Study 1: Using the marketed apps with smart glasses. This study consisted of the following activities:

Getting familiar with the smart glasses. After signing a consent form and filling out a demographic questionnaire, each participant watched a 3-minute video explaining how to use the smart glasses. The video provided general information on the device and its touchpad's buttons. Participants were then asked to: 1) take photos with the camera, and 2) navigate through a map with a web browser. This stage ensured that all participants knew how to interact with the smart glasses.

Using the marketed apps. Afterward, participants had to interact with the two commercial apps. Each participant was given a printed instruction sheet on how to use the apps and an explanation on the activities to be performed. In the first activity, they had to use **pARtum** to visualize and analyze interactive 3D objects using some AR markers. The second activity consisted of using **Augumenta Virtual Surface**. First, participants had to configure the app through the smart glasses. This required using the glasses' camera and some hand gestures. Participants were then able to superimpose a virtual keyboard onto their palm by closing and opening their fist. They used this keyboard to take brief notes, simulating an in-class note-taking activity. Participants spent about 15 minutes to complete this first experiment.

Closing Interview & Questionnaires. Participants were then asked to share their impressions in a semi-structured interview. They also filled questionnaires on different aspects of their experience (e.g., workload, emotions).

Study 2: Using the STEM Education AR app with smart glasses.

In the second experiment, participants had to use the smart glasses to interact with an AR app we developed (Figure 3) to work on four STEM tasks. In the **Science** task, six AR markers were used to visualize, identify, and link some chemical elements of the periodic table. Different combinations of the AR markers led to the animations of specific chemicals. The second activity focused on **Technology** concepts. Participants scanned an AR marker to work with a block-based visual program to control a robot. The **Engineering** activity involved displaying the components of a physical Arduino board. Participants used the trackpad to separate, analyze, and interact with each of board components. In the **Mathematics** activity, participants had an AR marker showing a frequency and a bivariate normal distribution, whose shapes could be changed via sliders. This second experiment lasted about 15 minutes.

After completing the activities, participants had to fill out four questionnaires and share their experiences, preferences, and emotions about the app in a semi-structured interview.

D. *Data Collection and Analysis*

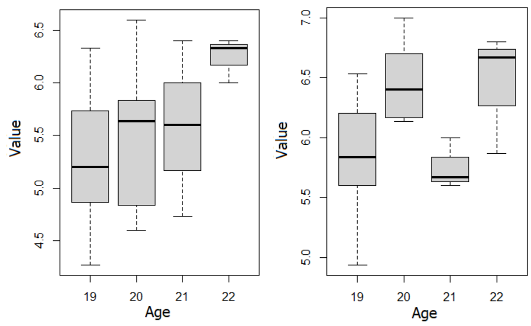
We used questionnaires to collect participants' perceptions on a) usability, b) technology acceptance, c) overall experience and d) emotions. After completing an experiment, each participant was asked to fill in the questionnaires: a) Post-Study System Usability Questionnaire (PSSUQ), b) Unified Theory of Acceptance and Use of Technology (UTAUT), c) Nasa Task Load Index (NASA-TLX) and d) and Emotions questionnaire. Each questionnaire item was rated using a 7-point Likert scale (1=Strongly Disagree and 7=Strongly Agree), except for the NASA-TLX questionnaire, which was scored on a [1—20] range (1=Very Low and 20=Very High). A closing semi-structured interview asked participants on questions related to the two studies. The interviews were recorded, transcribed and iteratively qualitatively coded through a thematic analysis [16] by two researchers, until a unified coding scheme was reached.

V. RESULTS

A. *Demographic Analysis*

The median age of the participants (n=24) was 20, with the youngest being 19 and the oldest 22. An analysis of the demographic data we collected reveals that 12.5% of participants had no AR/VR knowledge, 58.3% had no AR/VR practical experience, and 29.2% had AR/VR knowledge with some limited mobile experience.

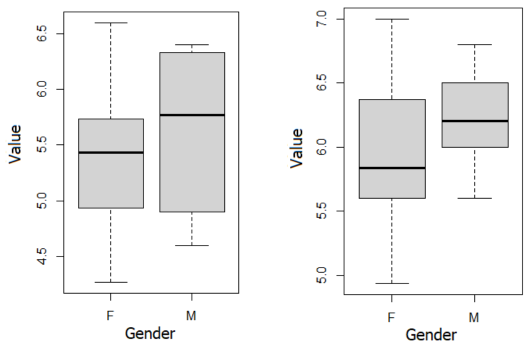
We did not find evidence that age affects the average usability of smart glasses in neither Study 1 (Figure 5a) nor Study 2 (Figure 5b).



(a) (b)

Figure 5. Usability (PSSUQ) by Age: (a) Study1 (b) Study 2

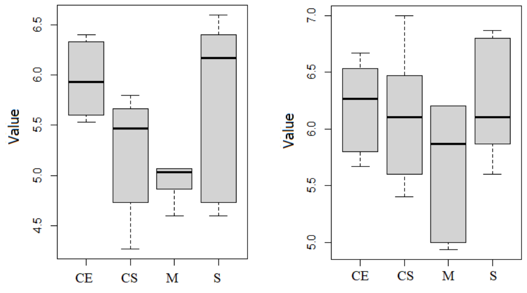
Gender did not affect the average usability of the smart glasses in Study 1 (Figure 6a) or Study 2 (Figure 6b).



(a) (b)

Figure 6. Usability (PSSUQ) by Gender: (a) Study1 (b) Study 2

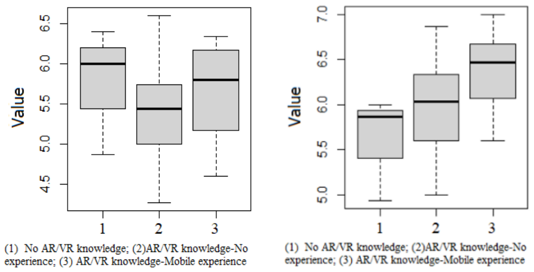
There is no evidence that participants' academic program affects the average usability of smart glasses in Study 1 (Figure 7a) or Study 2 (Figure 7b).



(a) (b)

Figure 7. Usability (PSSUQ) by STEM Careers: Chemical engineering, Computer Science, Mechatronics, and Statistics - (a) Study1 (b) Study 2

Finally, there is also no statistical evidence that the participants' level of AR/VR knowledge affects the average usability of smart glasses in any of the studies (see Figure 8).



(a) (b)

Figure 8. Usability (PSSUQ) by level of AR/VR knowledge - (a) Study1 (b) Study 2

B. Quantitative analysis

Independent samples from each study were used to analyze the scores on each dimension of the questionnaires.

The average scores for the dimensions of the **PSSUQ** questionnaire are shown in Figure 9. Overall, the scores associated to the user experience dimensions were lower in study 1 than in study 2: *system usefulness* (5.5 versus 6.00), *information quality* (5.60 versus 6.38), and *interface quality* (5.88 versus 6.38).

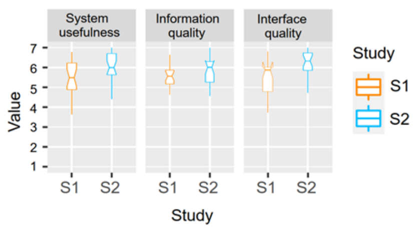


Figure 9. Average scores of the PSSUQ questionnaire for study 1 and 2.

The average scores of all participants for the dimensions of the **NASA-TLX** questionnaire are shown in Figure 10. In Study 1, the *Physical demand* had the lowest perceived workload (5.00). This was followed by *Performance* (6.50) and *Mental demand* (9.00). Both *Frustration* and *Temporal demand* were rated at 10.00, and *Effort* reached the highest score (11.00). A similar pattern is observed in study 2, revealing that *Physical demand* had 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). In both studies, the overall result of the NASA-TLX questionnaire reveals that participants experienced medium levels of workload.

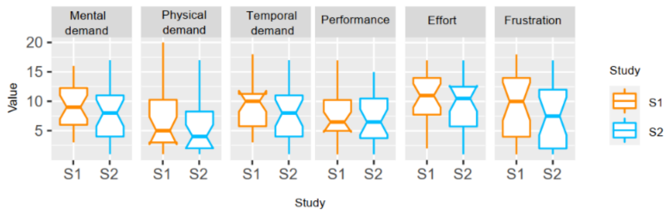


Figure 10. Average scores of the NASA-TLX questionnaire for study 1 and 2.

The average scores for the dimensions of the **UTAUT** questionnaire are plotted in Figure 11. Study 1 shows that the lowest average scores correspond to *Facilitation condition* (4.67), *Effort expectation* (5.12), and *Performance expectation* (5.75). The other dimensions were rated at the upper end of the range: *Behavioral intention* (6.00), *Social influence* (6.33), and *Attitude* (6.38). In study 2, the lowest average score corresponded to *Facilitation condition* (5.33). The remaining dimensions were rated with higher scores: *Effort expectation* (6.00), *Behavioral intention* (6.00), *Performance expectation* (6.50), *Attitude* (6.75), and *Social influence* (6.83). This outcome suggests that study 2 resulted in slightly higher levels of technological acceptance than study 1.

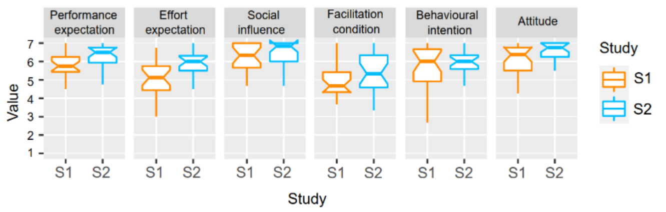


Figure 11. Average scores of the UTAUT questionnaire for study 1 and 2.

Finally, the average scores for the participants' **emotional responses** are shown in Figure 12. The six basic emotions of the questionnaire, rated with a [1 −7] scale, defined two groups. In Study 1, Negative emotions received low scores: *Anger* (2.00), *Fear* (1.00), *Dislike* (1.00) and *Sadness* (1.00). The opposite is true for positive emotions: *Joy* (5.50) and *Surprise* (5.00). These scores suggest that the smart glasses induced a mostly positive emotional response. In Study 2, Negative emotions received also low scores: *Anger* (1.00), *Fear* (1.00), *Dislike* (1.00) and *Sadness* (1.00). On the other hand, positive emotions received the highest average scores: *Joy* (6.00) and *Surprise* (5.00). Overall, these results indicate that the *STEM Education* app induces a positive emotional response in the participants.

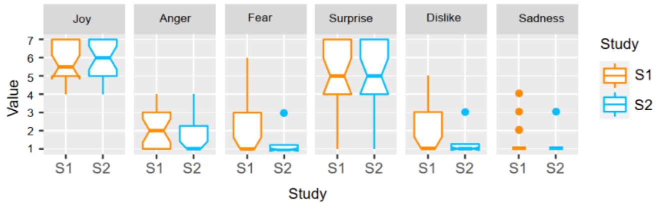


Figure 12. Average scores of the Emotion questionnaire for study 1 and 2.

We also analyzed the internal consistency (or reliability) of the items of each questionnaire we used. To this end, we resorted to Cronbach's alpha [17]. The results of the reliability test for each questionnaire were as follows:

- Study 1: PSSUQ = 0.85, NASA-TLX = 0.58, UTAUT = 0.90, and emotions = 0.45.
- Study 2: PSSUQ = 0.85, NASA-TLX = 0.84, UTAUT = 0.97, and emotions = 0.36.

The construct reliability coefficients (i.e., those above 0.70) suggest that the questionnaire items have high internal consistency, with the exception of the NASA-TLX for Study 1 and the Emotions questionnaire for Study 1 and 2.

C. *Qualitative analysis*

In study 1, participants had an overall positive attitude toward the smart glasses. Their comments confirm their questionnaire ratings: "*Having a 3D object that you can move was incredible.*" [P01]; "*I found very interesting using my body and the cards to explore the brain.*" [P04]; "*Navigating the streets of another city without physically moving was very interesting.*" [P22]; "*It was an incredible experience because I could see everything in 3D.*" [P12]. However, a few comments also highlighted unexpected behavior: "*It was frustrating because the glasses didn't fit me.*" [P03]; "*I had to do everything with one hand, because I had to hold the glasses with the other.*" [P17]; "*The glasses were too big for me.*" [P21]. Regarding the apps, participants enjoyed using the AR markers with **pARtum**. On the contrary, in most cases, the interaction with **Augumenta Visual Surface** was problematic. Our participants' interaction with the virtual keyboard was mainly a trial-and-error exercise, as illustrated in this exemplary statement: "*I could not even write my name. It would just end whatever task I was working on.*" [P19].

In Study 2, students had good experiences and positive attitudes toward the app in each scene: **Science**: "*You could see how the atoms come together to form reactions.*" [P17]; "*I found it very dynamic.*" [P23]. **Technology**: "*Very interesting to see how I can program the robot, so it moves as I tell it to.*" [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].

VI. Discussion

Our research analyses the user satisfaction of smart glasses and the STEM Education app. The average score of the questionnaires suggest that most participants were satisfied with the glasses and the AR app.

PSSUQ measures suggest that participants were satisfied after using the smart glasses and the STEM Education app for the first time **(RQ1).** The scores of this questionnaire shows also that the developed app provides a better UX and satisfaction than the two commercial apps we used in Study 1. The **UTAUT** questionnaire indicates a good level of technological acceptance of the STEM Education app **(RQ2)**, but it also suggests that the smart glasses' features associated to the *effort expectancy* and *facilitation condition* need to be improved. In addition, we note that participants' interactions with the Augumenta virtual keyboard tends to have a negative impact on the reported scores.

The results of the **NASA-TLX** questionnaire are supported by previous research with novice smart glasses users (e.g., [18]) and users who have used AR apps with smart glasses [19].

Overall, the quantitative observations from the questionnaires align with the participant statements reported in our qualitative analysis. Likewise, the results show that participants experienced a medium workload in both studies **(RQ3)** when they interact with the smart glasses and the app. Nevertheless, participants saw great potential of using the AR app for the four STEM areas. Finally, most students showed positive emotions after their first experience with smart glasses and the STEM Education app **(RQ4)**.

The results of the demographic analysis on age, gender, students' academic program, and their level of AR/VR knowledge is considered reasonable, due to the fact that the data was collected in a higher education institution. It could also be identified that there is no evidence that these characteristics affect the average usability in both studies.

In Study 1, despite some comments on the form factor and ergonomics of the of the Epson Moverio BT-300 (especially from students wearing glasses), the scores associated with negative emotions were not significant. Our qualitative analysis corroborates this observation. Some students did not feel comfortable because they stated that the device did not fit their face properly. We should note, however, that these observations may vary with other devices. In study 2, students mentioned that when using the AR markers, some objects were displayed too close, and the AR marker had to be moved away. They also stated that they expected additional features in the app. Nonetheless, the scores associated with negative emotions were not significant.

Although the same group of students participated in both studies, Study 1 had lower quantitative scores due to the form factor issues that arose with the smart glasses. In Study 2, they probably got use of this ergonomic issue or found ways to overcome it. It is also possible that users found the STEM Education app more relevant and enjoyable for e-learning settings. One of our main concerns was the fact that the study would be too long and could lead to a gradual decrease in students' performance. The results show that this was not the case, since the UX measures we observed improved over the time.

VII. CONCLUSIONS

In this work, we analyzed the UX of STEM students after using smart glasses and an AR app. The study was motivated by the scarcity of UX evaluation with smart glasses in STEM educational contexts. This motivated the development of an AR app that supported learning of specific STEM topics. We set out to understand how this technology affects the learning process of the participants. To this end, we evaluated several usability-related aspects of the smart glasses, such as technological acceptance, user experience, and emotional response. We also conducted semi-structured interviews and used standardized questionnaires such as the Post-Study System Usability Questionnaire (PSSUQ), the Unified Theory of Acceptance and Use of Technology (UTAUT); the NASA Task Load Index (NASA-TLX), and an Emotions Questionnaire. They were applied to assess usability, technological acceptance, overall experience, and emotional response of both the Epson Moverio BT-300 smart glasses and the STEM Education app we developed.

The scores of Study 1 showed good UX performance, despite the limitations imposed by some form factor issues of the smart glasses. In Study 2, we explored whether the STEM Education app provided a different UX. The results show that the UX in Study 2 is higher than in Study 1.

We also found out that the user interface of our app was fit for purpose, as users were able to take advantage of the augmented information in their learning activities. The main demographic factors (age, gender, academic program, and level of AR/VR experience and knowledge) did not seem to affect the user satisfaction with the smart glasses or the STEM Education app. Future research will explore improving the user interface of our app and tackling the ergonomic issues of smart glasses. Also, we plan to include more students and perform inferential statistics on a longitudinal study.

This work suggests that the AR applications have the potential to facilitate the learning process of scientific concepts, especially if smart glasses are used in combination with AR apps.

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