# Usability Principles for Augmented Reality Applications in Education

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**Summary**
It is challenging to select appropriate technology in education to interact with students in today's digital world. Especially when the technologies used at home on smart devices like tablets and mobile phones are very advanced, on the other side, it may be more challenging to find sharing technology in the classroom. One of the ways is to use new technologies like Augmented Reality (AR). The current study aims to develop usability principles for the development and evaluation of education using AR technology applications. We develop usability principles for AR applications by analyzing existing research about heuristic evaluation methods, design principles for AR systems.
***Keywords:***
*Augmented reality, Principles component analysis, Education, Usability principles quantization errors.*

## 1. Introduction

Today, with the significant advancement in technologies, education is greatly affected and quickly launched in a new direction that will change the way learners learn and their teaching methods. Nowadays, the technologies used at home on tablets and mobile phones are very advanced so, it is not easy to find appropriate ways for students to interact with education. So, we need to use new technologies, such as tablet devices, used in the classroom to improve learning [1]. AR is among the technologies that have made headlines in recent years and from which education will be significantly benefited. The AR system allows the merging or "supplementing" real-world objects with virtual objects or overlapping information. As a result, virtual objects like the real world coexist in the same space. However, augmented reality can be used for all senses, such as touching, hearing, and smell, not just limited to the sense of sight [2].
The nature of AR and improvements added to them recently thanks to various technological developments allows for a new type of interactive education in which the learner participates. Some user experiences and usability issues must be solved to make this technology acceptable in learning and teaching. AR applications suffer different issues, unlike existing desktop teaching applications. So, developing applications for AR requires different considerations of design and development from traditional desktop apps. Current studies in augmented reality discuss hardware, performance or technology, but lack research on usability principles [3]. In this paper, we followed an organized method to determine usability principles that must be considered for developing AR applications for education.

## 2. Literature Review

### 2.1 Usability of Augmented Reality Applications

Swan et al. [4] research on usability principles of AR. They found only 14.3% of studies on user-centred design under the light of human-computer interaction (HCI) and only 7.9% on general use. Then the researchers classified user-centred AR studies into three groups. The first group understands user perception and recognition of AR operations, and the second one measures the user's task performance.

Moreover, the third one communicated with AR users. They found a lack of research about user interface and interaction from a user-centric point of view. Another researcher, Dünser et al. [5], expanded the work of Swan and Gabbard work. They worked on the AR studies done up until 2007 and found that only 10% had conducted user-performed AR experiments. Also found that there were only 41 studies on actual usability, excluding studies on performance and perception point of view and recognition.

### 2.2. Usability of AR applications in Education vs traditional applications in terms of interactivity, device handling, etc.

Arezoo Shirazi et al. [6] incorporating mobile context-aware visual simulation into STEM education, they conclude from their platform that visualizes a mobile augmented reality to (1) enhance the contents of the

Manuscript received December 5, 2021
Manuscript revised December 20, 2021
https://doi.org/10.22937/IJCSNS.2022.22.1.8

student's textbooks with computer-generated virtual multimedia and graphics, and (2) the platform allows students to interact with context-aware simulated animations better than traditional instruction and information delivery methods. Also, Ernest Redondo, Francesc Valls et al. [7] experiment has demonstrated that using visual systems is more motivating for students and improves the quality of their final projects and their final academic results.

Kunyanuth Kularbphettong et al. [8] used AR technology to manage learning in classrooms, and they found that students give more attention to learning than before.

Jun Lee et al. [9] made a simulator for veterinary education based on augmented reality; the result of their performance evaluation showed that the proposed system enhances performance compared to conventional approaches.

On another side, Iulian Radu [10] found that user motivation remains significantly higher for the AR systems (vs the non-AR alternative). From a literature review of 26 comparative AR publications, she concludes that there is a need to generate guidelines to design effective educational AR. Other research Phil Dingman et al. [11] conclude that AR is eligible to be used in educational environments, and they found that each AR application is unique, and therefore the benefits of AR may not apply in each context. Each application has to be implemented thoroughly to prevent drawbacks in user interaction.

According to Afshan Ejaz et al. [12], there are many differences between traditional GUIs and the AR-based user interface. So, we should develop a better insight to use existing usability principles.

### 2.3. Students facing problems while using AR applications

We studied existing research on AR applications and listed some usability issues as pointed out by various researchers in Table 1. The studies reviewed involved educational AR applications.

TABLE 1. EXAMPLES OF THE USABILITY ISSUES EXPERIENCED BY STUDENTS.

| Reference | Year | Identified Problems |
|---|---|---|
| [13] | 2007 | Cognitive overhead in mastering the interface, especially in educational applications, Technical issues (e.g., software robustness) |
| [7] | 2014 | Lack of time in the initial explanation Workgroups, Accessibility to the last generation, more accessibility to software, Problems reading help files, Tutorials with low detail, more time to practice, Difficulties to read, AR marks outside Schedule of the workshop, Problems with the deadlines |
| [14] | 2017 | Difficulty orienting while playing the game, Difficulty orienting while fixing tracking, Strained body postures in older students (7-8 and 9-10 years old), Difficulty recovering from tracking loss, Bump or tripping Interruption due to self-distraction. |
| [15] | 2018 | Problems to interact with the application and accomplish all the tasks, writing using the virtual keyboard on the mobile phone screen. |
| [16] | 2020 | A) Challenges relate to the user interface:<br>1. AR Browser: Limited user engagement and motivation, Non-adjustable user viewpoint, Non-adjustable virtual content.<br>2.3D User Interface: Require visibility for interaction, Smaller 3D UI in small display devices, Lack of physical feedback.<br>3. Tangible User Interface: Difficulties in multitasking when holding TUI, Limited interaction area.<br>4. Natural User Interface: Restricted movement when using body sensors requires motion-tracking accuracy; some natural interaction techniques require training.<br>5. Multimodal User Interface: Increases battery usage, Increases AR device weight.<br>B) Challenges relate to Virtual Content:<br>1. Offline Content: Virtual content change update is limited to a single user, Not suitable for online collaboration.<br>2. Online Content: Require a fast network to prevent lag, requires security measures to protect shared virtual content, require security measures to maintain and control the user field of view. |

Hence, we conclude that in usual schools, the student's different concepts in different grades. Thus, the application designers should understand the usability of target students as per their grade levels [3]. Then we conclude that the researchers are unclear about the usability principles to be used to develop AR applications in education, and the issue is because there are no defined usability guidelines for developing AR applications in education.

## 3. Development of Usability Principles for Augmented Reality Application

We conclude in our study that there is a dearth of literature on usability principles for applying augmented reality in education. Therefore, we have developed usability principles. In the first stage, we conducted a literature review to synthesize current usability principles. In the second phase, we had a meeting with experts to discuss specific usability principles. In the third stage, we classified the examined usability principles based on the results of the principal component analysis. The framework for our research is shown in Figure 1.

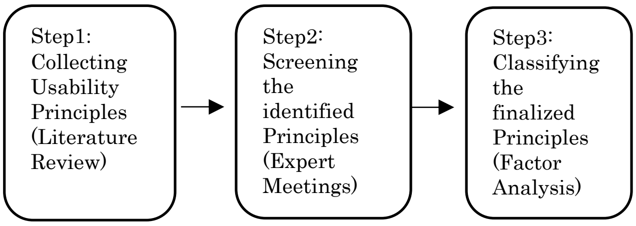


Fig. 1 Research framework

## 3.1 Usability Principles for Augmented Reality Application

In this study, we present principles for new forms of usability evaluation by considering the properties of educational AR applications, as discussed in section 2.1. For doing so, we collected the existing principles from 11 literature reviews of John D. Gould and [17], Andreas Dϋnser et al. [18], Beth F. Wheeler Atkinson et al. [19], David Pinelli et al. [20], Sang Min Ko et al. [21], Iulian Radu et al. [10], Tristan C. Endsley et al. [22], Lemuel Soh et al. [23], Afshan Ejaz et al. [12], Minghui Sun et al. [24], Neha Tuli et al. [3]. The identified principles are listed in Table 2.

John D. Gould and [17] identified three usability principles. The principles they identified were early Focus on Users and tasks, empirical Measurement, and iterative Design. In another study, Andreas Dϋnser et al. [18] proposed eight usability heuristics, including Affordance, Reducing cognitive overhead, Low physical effort, Learnability, User satisfaction, Flexibility in use, Responsiveness, and feedback, Error tolerance. The author's Beth F. Wheeler Atkinson et al. [19] highlighted some of the issues encountered while developing AR applications which are software- user Interaction, learnability, cognition facilitation, user control, and software flexibility, system-real world match, graphic design, navigation, and exiting, consistency, defaults, system-software interaction, help and documentation, and error management. David Pinelli et al.[20] mentioned that the AR application should provide consistent responses to user's actions, allow users to customize video, audio, and speed settings, provide predictable and reasonable behaviour for computer-controlled units, provide unobstructed views appropriate to current user actions, allow users to skip frequently inoperable and repetitive content, providing intuitive and customizable input mappings, providing easy-to-manage controls that have an appropriate level of sensitivity and responsiveness, providing users with application status information, providing guidance, training, and helping to make visual presentations that are easy to interpret and reduce the need to careful management. Sang Min Ko et al. [21] suggested some design principles include multimodality, enjoyment, familiarity, visibility, hierarchy, defaults, recognition, predictability, learnability, consistency, error management, help and documentation, user control, personalization, feedback, direct manipulation, responsiveness, low physical effort, context-based, exiting, navigation and availability. Iulian Radu et al. [10] mentioned that must the content is represented in novel ways, multiple representations appear at the appropriate time/space, the learner is physically enacting the educational concepts, attention is directed to relevant content, the learner is interacting with a 3D simulation, interaction and collaboration are natural. Tristan C. Endsley et al. [22] selected some usability principles which can be used for designing AR applications, which are fitted with user environment and task, form communicates function, minimize distraction and overload, adaptation to user position and motion, alignment of physical and virtual worlds, fit with user's physical abilities, fit with user's perceptual abilities, accessibility of off-screen objects, accounting for hardware capabilities. Lemuel Soh et al. [23] suggested some principles, including fast information response time and infrastructure availability, Resource discovery services, Resource distribution services, Intrinsic security, Seamless mobility, and Scalable content distribution. The authors Afshan Ejaz et al. [12] proposed the following principles: affordance or perceived affordance, visibility and natural mapping, low physical effort, learnability, user satisfaction, feedback, error tolerance, reducing cognitive burden, flexibility, simplicity. Minghui Sun et al. [24] suggested a more vivid approach, especially for children to study and acquire knowledge, real-time interactions between young children and the educational strategy, Better precision of the hand gesture recognition. Neha Tuli et al. [3] reviewed the existing literature and suggested principles for usability augmented reality in a mobile environment for Kindergarten. Which accuracy of game content, effectiveness to achieve the outcome, efficiency in learning, learnability, User-satisfaction, short-term memory load, procedural and semantic memory, user-oriented, customizability, aesthetic and minimalist design, consistency, the relationship between the real world and virtual objects, multi-modality, enjoyment, interactive, skippable non-playable content, design dialogues to yield closure, simplicity, context-based, error management, early test, help, and documentation, low physical effort.

TABLE 2. COLLECTED USABILITY PRINCIPLES.

| Reference | Principles |
|---|---|
| John D. Gould, 1985 | Early Focus on Users and Tasks, Empirical Measurement, iterative Design. |
| Andreas Dϋnser, | Affordance, Reducing cognitive overhead, Low physical effort, Learnability, User satisfaction, Flexibility in use, Responsiveness and feedback, Error tolerance. |

| | |
|---|---|
| 2007 | |
| Beth F. Wheeler Atkinson, 2007 | Software- User Interaction, Learnability, Cognition Facilitation, User Control & Software Flexibility, System-Real World Match, Graphic Design, Navigation & Exiting, Consistency, Defaults, System-Software Interaction, Help & Documentation, and Error Management. |
| David Pinelli, 2008 | Provide consistent responses to the user's actions, Allow users to customize video and audio settings and speed, Provide predictable and reasonable behaviour for computer-controlled units, Provide unobstructed views that are appropriate for the user's current actions, Allow users to skip non-playable and frequently repeated content, Provide intuitive and customizable input mappings, Provide controls that are easy to manage, and that have an appropriate level of sensitivity and responsiveness, Provide users with information on application status, Provide instructions, training, and help, Provide visual representations that are easy to interpret and that minimize the need for micromanagement. |
| Sang Min Ko, 2013 | Multimodality, Enjoyment, Familiarity, Visibility, Hierarchy, Defaults, Recognition, Predictability, Learnability, Consistency, Error management, Help and documentation, User control, Personalization, Feedback, Direct manipulation, Responsiveness, Low physical effort, Context-based, Exiting, Navigation, Availability. |
| Iulian Radu, 2014 | Content is represented in novel ways; multiple representations appear at the appropriate time/space, the learner is physically enacting the educational concepts, attention is directed to relevant content, the learner is interacting with a 3D simulation, interaction and collaboration are natural. |
| Tristan C. Endsley, 2017 | Fit with user environment and task, Form communicates function, minimize distraction and overload, adaptation to user position and motion, alignment of physical and virtual worlds, fit with user's physical abilities, fit with user's perceptual abilities, accessibility of off-screen objects, Accounting for hardware capabilities. |
| Lemuel Soh, 2018 | Fast information response time and infrastructure availability, Resource discovery services, Resource distribution services, Intrinsic security, Seamless mobility, and Scalable content distribution. |
| Afshan Ejaz, 2019 | Affordance or Perceived affordance, Visibility and Natural Mapping, Low Physical Effort, Learnability, User Satisfaction, Feedback, Error Tolerance, Reducing Cognitive Burden, Flexibility, Simplicity. |
| Minghui Sun, 2019 | A more vivid approach, especially for children to study and acquire knowledge, Real-time interactions between young children and the educational strategy, Better precision of the hand gesture recognition. |
| Neha Tuli, 2020 | Accuracy of game content, Effectiveness to achieve an outcome, Efficiency to learn, Learnability, User-satisfaction, Short-term memory load, Procedural and semantic memory, User-oriented, Customizability, Aesthetic and minimalist design, Consistency, Relationship between the real world and virtual objects, Multi-modality, Enjoyment, Interactive, Skippable non-playable content, Design dialogues to yield closure, Simplicity, Context-based, Error management, Early test, Help, and documentation, Low physical effort. |

After studying the existing literature and collecting 112 usability principles, we conducted a meeting with five experts having UI/UX experience of 3-4 years to discuss the standards of the collected principles. We selected 20 principles by deleting the duplicate entries and combining the related ones. Finalized Usability Principles after deleting the duplicates and integrating the related ones are Efficiency to learn, Affordance, Effectiveness to achieve the outcome, Low physical effort, Learnability, User satisfaction, Flexibility in use, Responsiveness and feedback, Error management, Early test, Familiarity, Visibility, Help and documentation, Consistency, User control, Personalization, Interaction and collaboration are natural, Simplicity and fit with user's perceptual abilities, Customizability, Multi-modality.

Then, we classified the obtained principles through a classification system. One hundred teachers from 8 different schools with 3-4 years of experience participated in the process. We used an inter-relationship matrix to identify the relationship between each usability principle. We applied the exploratory factor analysis test on the 20 obtained principles to obtain the results. In this paper, every factor comprised principles with a factor loading of at least 0.6 and rejected those with less than 0.6. As a result of principal component analysis (see Table 3), the principles were categorized into two groups (Fig. 2). The definition of the created groups is as follows:

1. Student-cognition: includes usability principles to intellectual aspects which improves thinking skills of the students and help them like learnability, efficiency, low physical effort, early test, etc.

2. Student interaction and support: This includes principles that define students' interaction with the application and provide information to students and support them, such as user control, help and documentation, visibility, customizability.

Table 3. Results Obtained from a Principal Component Analysis with Varimax Rotation.

**Component Matrix[a]**

| | Component | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Consistency | -.876 | | | |
| help and Documentation | .860 | | | |
| Error management | .860 | | | |
| user control | .860 | | | |
| Personalization | .860 | | | |
| Multi-modality | -.830 | | | |
| Familiarity | -.714 | | | |
| Visibility | -.714 | | | |
| Customizability | -.691 | | | |
| Early test | | .894 | | |
| Efficiency | | .894 | | |
| Effectiveness | | .894 | | |
| Affordance | | .823 | | |
| Learnability | | .739 | | |
| Low physical effort | | .696 | | |
| User satisfaction | | .684 | | |
| Flexibility in use | | .679 | | |
| Interaction and collaboration | | | .908 | |
| Simplicity | | | .908 | |
| Responsiveness and feedback | | | | .607 |

Extraction Method: Principal Component Analysis.

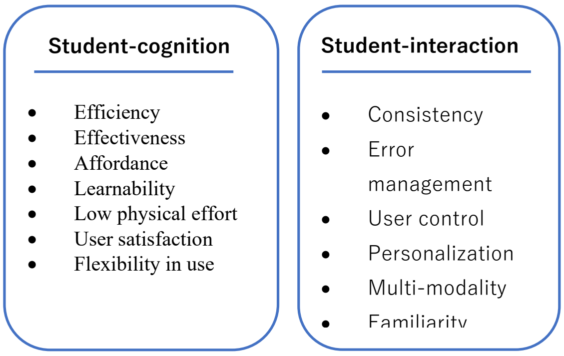


Fig. 2. Classified Usability Principles

## 4. Conclusion

In our work, we identified the existing literature on usability principles to develop usability principles for augmented reality applications for education and the design of augmented reality applications. We developed 20 usability principles for designing augmented reality applications for education. First, we analyzed 11 literature studies on AR learning applications. Then we gathered 112 principles that had been suggested, merged the related principles, and removed the duplicate entries. Finally, we used Exploratory Factor Analysis to classify and select the 20 definitive principles best suited to augmented reality applications for education in two groups. We expect that the proposed usability principles for developing educational learning applications using AR technology can be referenced. In the future, we will develop an AR application using the proposed principles and validate them through heuristic evaluation.

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