Usability Principles for Augmented Reality Applications in Education

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Summary
It is difficult to choose the right 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 hand, it can be hard to find sharing technology in the classroom. One way is to use new technologies such as augmented reality (AR). The current study aims to develop usability principles for developing augmented reality applications that are used in educational environments. We develop principles for the usability of augmented reality applications by analyzing current research on the principles of human-computer interaction, taking into account the characteristics of augmented reality applications.

Keywords:
Augmented Reality (AR), Human-Computer Interaction (HCI), Education, Usability, Principles, Design guidelines.

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]. Human Computer Interaction (HCI) design revolves around the impact of a design tool on the way people interact [4]. It also has great importance when used for developing systems and programs, as the strength and effectiveness of the application can be measured based on the user's ability to use it easily. Therefore, human-computer interaction improves the usability of applications by creating methodologies that give HCI designs the right shape so that they are effective for use by users [5]. 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. [6] 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. [7], 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.

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

Arezoo Shirazi et al. [8] 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 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. [9] 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. [10] used AR technology to manage learning in classrooms, and they found that students give more attention to learning than before.

Jun Lee et al. [11] 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 [12] 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. [13] 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. [14], 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
[7]	2007	Cognitive overhead in mastering the interface, especially in educational applications, Technical issues (e.g., software robustness)
[9]	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: 1. AR Browser: Limited user engagement and motivation, Non-adjustable user viewpoint, Non-adjustable virtual content. 2.3D User Interface: Require visibility for interaction, Smaller 3D UI in small display devices, Lack of physical feedback. 3. Tangible User Interface: Difficulties in multitasking when holding TUI, Limited interaction area. 4. Natural User Interface: Restricted movement when using body sensors requires motion-tracking accuracy; some natural interaction techniques require training. 5. Multimodal User Interface: Increases battery usage, Increases AR device weight. B) Challenges relate to Virtual Content: 1. Offline Content: Virtual content change update is limited to a single user, Not suitable for online collaboration. 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.

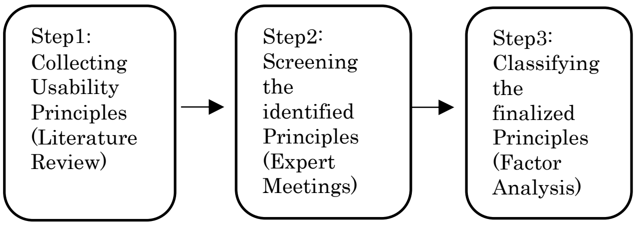

Fig. 1 Research framework

3.1 Usability Principles for Augmented Reality Application

In this study, we provide principles for new forms of usability assessment by considering the principles of human-computer interaction (HCI) and the characteristics of educational AR applications discussed in Section 2.1. Therefore, we collected the existing principles from 7 studies. We made sure that the principles in these studies were based on well-studied foundations, as well as that they were cited by other researchers in their studies. These studies were from Ben Schneiderman's book [15], Donald A. Norman [16], Andreas Dunker's paper [17], Michael Reese's book [18], Jacob Nielsen's book [19], Bruce Tognazini's book [20] and finally Mayhew's book [21]. The specific principles are listed in Table 2.

Ben Schneiderman [15], he wrote the eight golden rules for interface design in 2016, which can be applied in most interactive systems. These principles are striving for consistency, enabling frequent users to use shortcuts, providing helpful feedback, designing dialogs to lock them out, offering simple error handling, allowing actions to be easily reversed, supporting an internal locus of control and reducing short-term memory load. While Norman [16] wrote his book on how to create design as a connection between the user and the object, and how to improve the connection between them to make the experience of using the object enjoyable. His study is a suitable prelude to our study of the usability of AR applications in an educational environment in which the user is a student trying to learn new concepts. For our study, we chose the seven principles cited by the scientist to discuss their potential as a usability target in our case, including make things visible, get the mappings right and exploit the power of constraints. The researcher Andreas Dünser et al, [17] In their research, the researchers attempted to investigate the way in which some general human-computer interaction (HCI) guidelines are related to the emerging field of augmented reality (AR) application design. They have chosen a set of these general guidelines which are Affordance, Reducing cognitive overhead, Low physical effort, Learnability, User satisfaction, Flexibility in use, Responsiveness and feedback, Error tolerance. The basic design principles are identified by Rees et al. [18] as follows: Simplicity, Consistency, and Context. Jakob Nielsen et al. [19] produced 10 principles he calls usability inference, which is recommended to be followed by all user interface designers. They are system state visibility, user control and freedom, system-to-real-world matching, consistency and standards, and others. While Bruce Tognazzi [20] provides some guidelines for developing apps that he says will make the app easy to use, consistent, and clear. These guidelines are reducing latency, anticipation, discoverable interfaces, using metaphors, and others. Finally, Mayhew [21] mentioned the principles of software user interface design are ease of learning and use, task compatibility, user compatibility, durability, Invisible technology, product compatibility, WYSIWYG (what you see is what you get), workflow compatibility, simplicity, control, familiarity, straightforward manipulation, flexibility, responsiveness, protection.

TABLE 2 :COLLECTED USABILITY PRINCIPLES.

Reference	Principles
Schneiderman	Strive for consistency, enable frequent users to use shortcuts, offer informative feedback, Design dialogs to yield closure, offer simple error handling, permit easy reversal of actions, support internal locus of control and Reduce short-term memory load.
Donald A. Norman	use both knowledge in the world and knowledge in the head, simplify the structure of tasks, make things visible, get the mappings right, exploit the power of constraints both natural and artificial, design for error and when all else fails, standardize.
Andreas Dönser	Affordance, Reducing cognitive overhead, Low physical effort, Learnability, User satisfaction, Flexibility in use, Responsiveness and feedback, Error tolerance.
Rees	Consistency, Simplicity and Context.
Jacob Nielsen	Visibility of system status, Match between system and the real world, User control and freedom, Consistency and standards, Error prevention, Recognition rather than recall, Flexibility and efficiency of use.
Bruce Tognazzini	Anticipation, Autonomy Color Blindness, Consistency, Defaults, Efficiency of the User, Explorable Interfaces, Fitts's Law, Human Interface Objects, Latency Reduction, Learnability — Limit Tradeoffs, Use of Metaphors, Protect the User's Work, Readability, Track State, Visible Navigation.
Mayhew	User compatibility, Product compatibility, Task compatibility, Workflow compatibility, Consistency, Familiarity, Simplicity, Direct manipulation, Control, WYSIWYG (what you see is what you get), Flexibility, pensiveness, Invisible technology, Robustness, Protection, Ease of learning and use.

After studying the current literature and collecting 65 usability principles from general HCI principles, we convened a meeting with ten experts with 3-4 years of UI/UX experience to discuss the principles criteria collected. We chose 26 principles by eliminating repetitive principles and then merging similar ones. The principles of final usability after deletions and merges are simplicity, flexibility and efficiency of use, anticipation, user compatibility, ease of learning and use, reducing cognitive overhead, latency reduction, protect the user's work, use of metaphors, robustness, direct manipulation, visible navigation, user control and freedom, design dialogs to yield closure, explorable interfaces, consistency, match between system and the real world, reduce short-term memory load, familiarity, context, learnability, help and documentation, low effort, readability, affordance , error management.

Then we categorized the principles obtained through the classification system. 191 teachers from different school groups who teach at the elementary, middle and high school levels participated in this process, with experience of more than 3 years for 92% of them. We used a matrix of interrelationships to determine the relationship between each usability principle. We applied the exploratory factor analysis test to the obtained 26 principles to get the results. In this paper, each factor includes principles with a load factor of at least 0.3 and rejects those less than 0.3 As a result of principal component analysis (see Table 3), the principles are classified into four groups (Fig. 2). The groups created are defined as follows:

1.Personalization: The personalization set consist of principles related to users' application design to match their interests and tastes, be easy and flexible enough for them, anticipate what they want and look for when designing, etc.
2. Behavior: The behavior set consist of principles related to the interaction between users and the application and how to improve this interaction such as reducing response time and supporting manipulation, which allows the user to deal with objects freely, as well as trying to protect the work of the user and give him an appropriate amount of freedom while interacting with the application and so on.
3. Perception: The perception set consist of principles related to the cognitive aspects that the user needs to improve his learning speed on the application, to deal with the application as expected, to reduce the load of short-term memory, and so on.
4. Support: The support set consist of principles related to helping and supporting users such as providing useful information that achieves the goal, presenting elements and texts clearly and without errors, which helps the user to deal with the application correctly, managing errors, providing instructions when needed, etc.

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

Principles	Component			
	1	2	3	4
Simplicity	.766			
Flexibility and efficiency of use	.742			
Anticipation	.695			
User compatibility	.606			
Ease of learning and use	.502			
Reducing cognitive overhead		.763		
Latency Reduction		.697		
Protect the User's Work		.668		
Use of Metaphors		.622		
Robustness		.595		
Direct manipulation		.490		
Visible Navigation		.482		
User control and freedom		.381		
Design dialogs to yield closure			.635	
Explorable Interfaces			.632	
Consistency			.616	
Match between system and the real world			.593	
Reduce short-term memory load			.575	
Familiarity			.492	
Context			.389	
Learnability				.674
Help and documentation				.622
Low physical effort				.579
Readability				.551
Affordance				.551
Error Management				.403

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Personalization

1. Simplicity
2. Flexibility and efficiency of use
3. Anticipation
4. User compatibility
5. Ease of learning and use

Behavior

1. Reducing cognitive overhead
2. Latency Reduction
3. Protect the User's Work
4. Use of Metaphors
5. Robustness
6. Direct manipulation
7. Visible Navigation
8. User control and freedom

Perception

1. Design dialogs to yield closure
2. Explorable Interfaces
3. Consistency
4. Match between system and the real world
5. Reduce short-term memory load
6. Familiarity
7. Context

Support

1. Learnability
2. Help and documentation
3. Low physical effort
4. Readability
5. Affordance
6. Error Management

Fig. 2. Classified Usability Principles

4. Conclusion

In our work, we identified the existing literature on human-computer interaction principles to develop usability principles for the design of educational augmented reality applications. We have developed 26 usability principles to design augmented reality applications for educational environments. First, we analyzed 7 literature studies on human-computer interaction principles. We then collected 65 suggested principles, combined related principles, and removed duplicate entries. Finally, we used exploratory factor analysis to rank and select the final twenty-six principles most suitable for augmented reality applications for education in four groups. We expect that the proposed usability principles can be referenced for developing educational learning applications using augmented reality technology. In the future, we will develop an educational AR application using the proposed principles and validate them through heuristic evaluation.

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