Scoping the Window to the Universe; Design Considerations and Expert Evaluation of an Augmented Reality Mobile Application for Astronomy Education

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Abstract. Astronomy is a difficult to teach topic in primary education because its core concepts and topics have no relevance or fly contrary to pupils' limited observational perceptions. Augmented Reality (AR) experiential technologies offer a unique opportunity for enriching the observations of young pupils with engaging and scientifically valid educational content. This work describes the implementation details of a mobile AR application for astronomy education. A simple but pedagogically sound design and implementation process was followed and a detailed pupil evaluation strategy has been developed. The application has been presented to 15 primary school teachers and evaluated both on cognitive and affective axes. Cognitively, the difficulty of the content has been deemed adequate without challenge spikes, while affectively the application's only weakness has been identified as the lack of strong collaborative and personalization elements. These outcomes shall form the basis for future iterations of this work utilizing a participatory design strategy for a collaborative, personalized educational experience.

Keywords: Augmented Reality · Education technology · m-Education STEM · Astronomy

1 Introduction

Teaching Astronomy in primary school pupils is challenging because it is a field where personal experience goes contrary to contemporary scientific theory [1]. As it is established from cognitive theory children create their knowledge about the world and

M. E. Auer and T. Tsiatsos (Eds.): IMCL 2017, AISC 725, pp. 409–420, 2018.
https://doi.org/10.1007/978-3-319-75175-7_41

the universe based on two channels of information: personal observation and other people's explanations [2]. Detailing in this model a rigorous strand of research [2–6] has established three steps, three cognitive models for the establishment of scientifically based models of the universe and the world concepts. The first is the initial model which is based on children's own daily experiences (e.g., seeing the surface of the earth as a more or less flat place) which creates the first entrenchment of beliefs based on those early experiences. The second is the synthetic model where children reconcile their preconceptions with the scientific information as the children start receiving them from education and other contemporary information sources from adults. The third and final is the scientific model when this reconciliation is completed around adolescence where the scientific paradigm of world view becomes internalized and accepted as it emerges the most efficient way to interpret the young adult's more complex world interactions.

Especially in the previously described first stage, a source of serious problems can emerge if children do not get exposed early enough to the correct facts about the physical and astronomical phenomena through their daily life [7]. Children can then have so entrenched misconceptions that new scientific knowledge can get reinterpreted or skewed in accordance with preliminary models instead of the scientific ones [1, 6, 8]. It is exactly this experiential initial world view that can be assisted through the use of experiential means such as Augmented (AR) or Virtual Reality (VR).

AR utilizes advanced image recognition algorithms to track and superimposes over real objects virtual graphical objects through computer based visualizations, providing interactivity potential in real time for the user [9, 10]. Historically, the term AR has been coined by Boing in 1990, when, in a project, they devised this visualization technique to assist their workers in the assembly of their aircraft [11]. AR and VR [9], while utilizing both 3d content user immersion have significant differences. VR fully replaces the user's environmental perception with an artificial one, while AR only adds to the real world virtual objects. Thus AR can allow for outdoor activities as well as lower intensity (and thus overhead) experiential activities than VR [12, 13].

AR appears to be the correct mix of virtual and real field of simulations and feedback for teachers and learners [14]. It creates more authentic user experiences being able to tap into realistic, complex and tangible interplays between the virtual and the real [15].

"Tangible interface" is a term denoting a transparent UI design allowing the user to manipulate the real markers of AR and affect changes in the virtual superimposed content. This kind of interaction provides "sensorimotor feedback" [16]. This kind of manipulation alleviate the immediacy barrier between the user and the content that exists through standard mouse based interactions of virtual (computer generated) content [16, 17]. As has been postulated in the literature, AR interfaces radically change the way that educational content is understood through transparent sensory immersion and interaction while not altering its core [18]. AR, thus, is the correct mix of real and virtual, in order to offer maximum educational benefits through the support of transparent interaction between the real and the virtual environment, utilizing the tactile-tangible interface metaphor interactivity for a smooth transition between the virtual and the real [19].

Several applications of AR have been developed from its inception. For example in entertainment storytelling, applications like MagicBook [20] allow reading of a traditional book while a handheld display projects virtual objects. The users still can use the book without the technology, tacitly turning the pages, however the AR content intensifies the experience. Specifically for education AR has been implemented for immersive experiential education topics like medicine to physics [21, 22]. Specifically in the latter and in overall Science Technology Engineering and Mathematics (STEM) fields have had specific applications. For example, augmented Chemistry consisted of a workbench and a screen that allowed users to understand atom or molecule structure by displaying it in 3D. Use of booklets, cubes and other image registration objects has been used according to necessity to allow immediate and tactile interaction with atoms and molecules [23]. In other educational endeavors, apps like ‘The Book of Colours’ [24] used headgear to teach children, through immediate visual feedback, the basic theory of color.

In astronomy education several applications have been made, exploring AR in teaching concepts such as earth-sun relationship teaching solistices and axial tilt, as well as explore the whole of the solar system in book based educational tools [18, 25].

In this context the idea was born to create a card based, AR mobile app, that would allow learners to tacitly interact with the object of the solar system, while at the same time being able to explore information about each of them. This paper describes both the implementation details of this endeavor as well as the first evaluation results from educational experts (teachers) that would be called to utilize such a medium in experiential, collaborative, learner centric educational episodes.

2 Methods

Implementation

The “Window to the Universe I” application used in this study is an augmented reality application that uses appropriate surveillance cards to visually display information about the celestial bodies that consist the solar system. Using the mobile phone’s camera, the application recognizes each card and digitally overlays the three-dimensional model of each planet, along with encyclopedic knowledge for it (Fig. 1A).

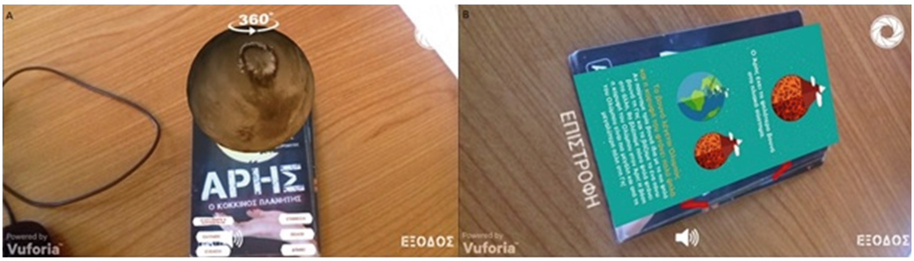

Fig. 1. Augmented reality interactive card with A. overlaid 3D planet and B. overlaid infographic.

The user has the ability through a tactile interface with his mobile phone to interact with the three-dimensional content (by rotating the card to see each planet from another angle) and to obtain information about the planets through infographics suitably designed for each age group (Fig. 1B). The application starts with the user's choice of age and the way he wants to interact with the material. The application enables the student to use interactive cards both in the previously described form and as a means of comparing the sizes of the basic planets. Specifically, approaching the two interactive cards, the planets depicted take their comparative size scale, while their rotation speed is also adjusted in proportion to their real size. Thus, the student acquires a direct view of the sizes and movements of the planets of the solar system. The application was developed in Unity utilizing the Vuforia AR package for it. The digital content included commercially available assets of the solar system (3D models of the planets) overlaid in small handheld cards (one for each planet). This was a core design decision of the approach as to engage the user/learner through the tactility of "holding" a realistically looking planet in her hands, being able to manually rotate and "look closer" at it. Furthermore, in each card representing the planet, core knowledge was inserted as information buttons at the bottom of the cards area. These buttons, press-able in the mobile device changed the digital content of the card, from a tactile model planet to a dashboard that provides concise information in the form of stylized infographics). The user can scroll this infographic through her mobile device and explore the information on her own. The application has been developed with content for 3 age ranges (selectable at launch) with increasingly complex and detailed content according to it. The material that was included in the application has been co-authored by an astronomy expert in collaboration with an educational expert, in order to offer both topic and age specific content and phraseology.

Evaluation

Instructional scenario

For the evaluation of the app in the context of a specific educational episode, two versions of an instructional scenario were created in order to be distributed to students of a control and an experimental group respectively. The instructional scenario was designed for 2.5 instructional hours and it was compatible with the curriculum of the 6th grade of the Greek Primary School education, as its topic is included as a specific thematic unit in the subject of Geography. The two versions of the scenario were developed by the teachers that will act as the facilitators of the evaluation teaching episodes. For the control group, the facilitators created relevant printed material that contained the digital information presented in the app "Window to the Universe". For the experimental group no printed material was included, as all the information was contained in the app itself. The instructive-methodological approach that is aimed to be practiced in both groups' instructional scenarios is the collaborative exploratory method, which aims to actively involve students in the learning process through group based exploratory knowledge building. In that fashion, learner initiative will be fostered and the teacher's role shall be supportive and coordinating.

Learner's evaluation tools

Evaluation of the students' performance in both groups shall be conducted in two axes, one cognitive, regarding knowledge retention, and another affective, regarding the engagement of the students with the subject matter through the two (conventional and AR enabled) teaching episodes.

The cognitive part of the evaluation involves assessment sheets that shall be provided to students after the end of the teaching episodes in order to determine whether the learning objectives have been achieved and to determine the extent to which learning has been accomplished. The assessment sheet was structured on 6 subjects which include multiple-choice questions, "True-False" questions, matching questions, and open-ended questions with graded difficulty. It was considered appropriate to incorporate a combination of questions, both open and objective-closed ones, in the assessment test. Open-ended questions evaluate the creative and synthetic ability of the learner. On the other hand, objective questions, if properly formulated, require the learner to recall information and also other superior cognitive skills. Thus, it was considered preferable to use a combination of questions so that the pupils shall respond as well as possible according to their abilities. The subjects of the assessment sheet were divided according to the type of the question and its difficulty.

The affective part of the evaluation involves a validated instrument, namely the Engagement Versus Disaffection with Learning scale [26] for testing the experimental and the control classes for homogeneity regarding the mood and disposition towards educational engagement. It also utilizes the AffectLecture app for immediate self-reporting classroom affective analytics [27] of student mood before and after an educational episode using one from five emoticons that best represented their affective state (Fig. 2).

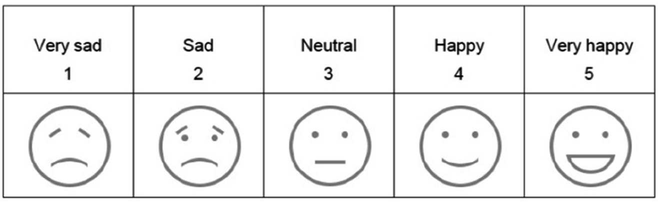

Fig. 2. AffectLecture emoticon scale

Teacher's evaluation

With the full battery of both the experimental procedure and the evaluation procedure in place the actual evaluation is expected to take place at a time close to the students' actual involvement with the subject matter in the formal curriculum. However before deploying the educational episodes an expert evaluation was conducted amongst primary school teachers. This evaluation also included both a cognitive and an affective axis.

The cognitive axis was covered through an assessment of the completeness and suitability of the student cognitive assessment tool. Specifically, 15 primary school teachers were called to review the student assessment questionnaire and report their opinions in a teacher oriented survey. The evaluation was based on the following topics: the level of difficulty of the questions, the degree of overlapping between the application's content and the course material of Geography's unit about the Solar System, the appropriateness of the kind of questions and their structure and finally the completeness of the educational content. Difficulty was graded in a 1–10 scale for each assessment question (to match standard student assessment grading) while the other aspects were graded on a standard 5 points Likert scale with 1 being strong subject disagreement and 5 being strong subject agreement.

The affective axis of the evaluation consisted of a teachers' questionnaire exploring what factors would make the "Window to the Universe" app more engaging to the user. After teachers' interaction with it for a minimum of 30 min they were called to grade several aspects of it that would increase its affective impact and engagement potential. These items were organized in 10 categories (Table 1) with topics in each that included generics like graphics and audio, down to specifics like autonomous navigation and user centric design. All these items were graded on a scale of 1–10 with 1 being the least influential to the users' engagement and overall affective impact and 10 being the most influential.

Table 1. Mobile app implementation aspects affecting engagement potential and affective impact

Aesthetics
Subjective attractiveness
Novelty
Time endurability
User involvement
User attention focus
Perceived usability
User collaboration
User personalization
User feedback immediacy

3 Results

Cognitive Axis

The teachers' questionnaire was answered by 15 primary school teachers 11 women and 4 men. Teachers were asked to grade on a scale of 1 to 10 the level of difficulty of each subject separately as a reflection of the overall level of difficulty of the app's educational content. Most of them agreed that the 3rd subject, which was a matching type exercise, had a higher level of difficulty, as well as the first one that required the correct classification of the planets according to their distance from the Sun. They considered the 5th subject, which was an open-ended exercise, easier than the others because of the fact that students could give varying answers, many of which would be accepted as correct. The graph below (Fig. 3) presents the answers of teachers regarding the level of difficulty of each subject.

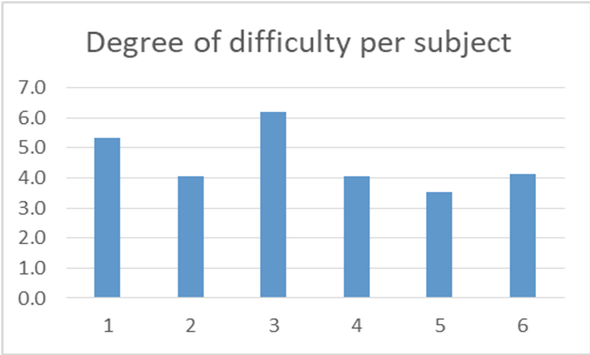

Fig. 3. Teachers' difficulty assessment for the app's topics as represented by the questionnaire.

The results from the specifics of the evaluation are summarized in Fig. 4. Specifically the content of the app, as reflected by the assessment sheet given to the students, overlapped appropriately, according to the teachers, the 6th grade Geography unit of the formal curriculum for the "Solar System" (Fig. 4A). Most teachers, as shown by the graph below (Fig. 4B), felt that the knowledge content was more than the content of the book's chapter, by approximately 41%–60%. Furthermore, most of teachers believed that the assessment methods that are going to be used for evaluation of the students' absorption of the app's material are very appropriate. In particular, responding to a five-point scale ranging from "no" to "very much," all teachers gave answers ranging from 3 to 5 (Fig. 4C).

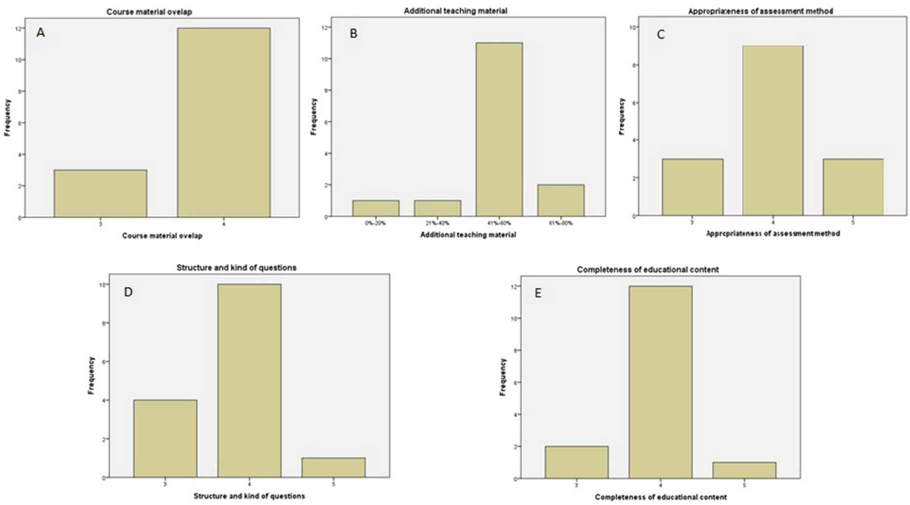

Fig. 4. Summary of teachers' assessment of app educational content and evaluation method as reflected by the cognitive content evaluation sheet.

Regarding the structure and type of questions that were selected on the assessment sheet, most teachers responded that they were quite good. In particular, responding to a five-point scale ranging from "no" to "very much," all teachers gave answers ranging from 3 to 5. Teachers' answers are shown in the graph below (Fig. 4D). Finally, in terms of educational content, the average of teachers responded that the content of the app as reflected by the cognitive content evaluation sheet was largely complete as it covered the full range of teaching subject and various aspects of it (Fig. 4E).

Affective axis

For this axis the same cohort of teacher's as previously was used. The teacher's grading of the various aspects that would improve the application's engagement and overall affective impact is summarized in Table 2. As can be ascertained by that, the aspects that received the highest attention from the teachers were the user collaboration and personalization capacity of the application. Specifically the teachers focused on even more customization, regarding not only the age range, but also the specific knowledges of the users of the application, as well as the inclusion of more collaborative tasks, in the application design.

Table 2. Teacher's perceptions regarding the augmenting of application's design aspects for increased engagement and affective impact

Affective impact categories	Teachers' score (STD)
Aesthetics	8.2 (1.8)
Subjective attractiveness	8.8 (1.3)
Novelty	7.5 (2.0)
Time endurability	8.2 (1.3)
User involvement	8.8 (1.4)
User attention focus	8.5 (1.7)
Perceived usability	8.8 (1.3)
User collaboration	9.9 (0.4)
User personalization	9.8 (0.4)
User feedback immediacy	8.2 (1.5)

The innovative aspect of the application was apparent to the teachers since the least important aspect to be improved in it was the novelty of the experience as well as improvements for time endurability.

Beyond this quantitative results a small number of these teachers (2) agreed to offer more detailed qualitative feedback in the form of unstructured interviews, describing their experiences and opinions about the strengths and weaknesses of the application.

The interview focused basically in highlighting the teachers' opinion concerning the functionality and the main characteristics of the app. As far as the aesthetics of the app are concerned, both participants pointed out that it is a sophisticated interface with impressive and interesting graphics, while the digital information that is presented, is legible and displayed in a linear and organized manner to the user. As for the functionality of the app, the participants seemed to agree that its use is simple by allowing the user to manage the material easily and quickly. In fact, one of them pointed out that one key factor of the app is that it allowed the user to manage the instructional information in the order and time he/she prefers and did not force her to study linearly the whole material. Concerning the content of the app, the teachers focused on the fact that it is covered in scope and depth with a critical scientific eye. They particularly emphasized that knowledge is being explored in a way that allows the learner to create his own learning path autonomously. Also, the approach of a complex and difficult subject such as that of the Solar System is reinforced by the app's diverse and playful concept, transforming the user's interaction with the content into an engaging and experiential activity. On the other hand, the coordinators stated certain weaknesses of the app agreeing that its load of data necessitates the installation of the app only on state-of-the-art mobile devices that meet high standards. Thus, the successful installation and use of the app may be difficult and the user has to possess the proper device and software. In addition, one of the coordinators said that in some cases the user is overloaded with the abundance of information with a risk of being dismantled. However, in general, the comments of both coordinators were positive, pointing out mightily that "Window to the Universe" it's about an innovative and interesting app that can engage the user in a multidimensional learning experience.

4 Discussion

Summarizing, regarding the cognitive teacher evaluation, we are coming to the following overall conclusions: teachers considered the level of difficulty of the evaluation sheet small to moderate. However, there were variations in individual subjects as they identified a greater degree of difficulty in close-ended questions such as matching and "True-False" questions, which required complex and abstract thinking, developed critical competence and co-thinking. On these topics students had to combine information from various parts of the app's content and to critically approach the questions.

Teachers felt that the types of questions that were chosen and their structure were very appropriate. In particular, different types of gradual difficulty questions were selected to challenge students' interest and help them all to respond as well as possible without exception, even those who may be experiencing special learning difficulties as well as those who learn at normal rates. In addition, they considered that the school content about the solar system was completely overlapped and outmatched by the applications content. In that context the participating teachers declared their extreme interest in discovering the results from the forthcoming learner evaluation.

Regarding the affective evaluation, the application has been evaluated very positively as a single-user engagement tool for involving the learner experientially into the subject matter. From the qualitative evaluation it became clear that the learner-centered, exploratory educational paradigm was very efficient and innovative as a means for a user to discover the solar system at her own pace. The need for collaborative content customized to each group according to their knowledges and their age was the core requirement for improving the application. While the technical overhead was mentioned as a weakness in the evaluation the rapid increase in processing power of mobile devices is going to alleviate very soon this weakness.

Successful educational episodes require a wide array of experts (technologists, teachers, students, artists, etc.) working in collaboration and are not straightforward regarding their deployment in the field [28]. Designing interfaces for children, transferring the material into effective AR experiences, adapting the experience for age and ability, designing for collaboration in the classroom are all topics open to research [7]. An approach that has been followed and that this work has also adhered to, was exploring the value that AR can offer to STEM education through the incorporation of "personalized lenses". This entails the inclusion of age- and ability-specific content on the target objects of the technological modality. Thus the experience becomes more accessible to various age groups and levels of familiarity with the subject, while allowing for an increased audience to participate. That way the road opens for educational collaboration potential in diverse learning environments, in and out of the classroom [29]. In that context, the idea of iterating with AR prototypes based on formal STEM curricula of varying "virtuality" for collaborative learning is not new. A step further, indeed, is the inclusion of participatory design processes with students and teachers [30]. This design paradigm has proven its merits in several occasions in the past. In educational interventions towards challenging target groups such as deaf students and people with dementia, participatory design at the early stages of it revealed unanticipated potential problems [31, 32]. In fact not following this methodology close enough at all design stages was something that was mentioned as a proven weakness in the course of the design process [32]. Participatory design processes in AR content for education has matured including checklists and rigorous predefined protocols in order to formally and efficiently support e.g. child oriented design [33] and definitive domain goals for the participation of both children and adults in these processes [30]. Furthermore, this design paradigm has been determined to be an excellent educational experience for the children included in it [34].

Given the previously outlined context, it must be noted that the next iteration of the application, that is going to be publicly released, shall integrate all the outcomes of this evaluation, as well as those from the forthcoming student evaluation. These outcomes form the basis for a next iteration of this application. This next iteration shall be the focus of a more massive, formative assessment of user preferences, as well as the appropriateness for various educational contexts by both teachers and pupils. In short this work is the first part of participatory content and user experience design process with the end goal of an effective personalized educational support tool for the experientially difficult topic of astronomy in the primary school age range.

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