Designing Interactions for Augmented Reality based Educational Contents

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1. Introduction: AR in Education

Education is one of the most natural areas of application of virtual reality (VR) technologies. The goal of VR, such as provision of compelling experience, goes particularly well with the “hands-on” approach to education. It goes without saying that this “hands-on” feeling is very important for lasting educational effects [1].

Like any digital contents, virtual reality can also eliminate many of the operational problems of teaching. Take an example of a chemical experiment. While the virtual experiment (e.g. in 2D or 3D) would probably be secondary and complimentary (in its effect) to carrying it out in the real world, the teachers would not need not worry about “petty” things such as cost, set-up, cleaning, and safety. The contents may even be self-driven and contain imaginary objects to make it more fun (e.g. a procedure explained by “Einstein” character).

General virtual reality systems require costly and still difficult-to-use multimodal displays and sensing devices to provide such “hands-on” feeling. Practically speaking, it will take some time for such systems to reach our classrooms. A viable alternative is the use of augmented reality systems (AR) instead. First of all, AR contents can be put to use in the real scene with relevance (e.g. AR based chemical experiment carried out on an actual laboratory workbench). Today, a reasonable system set-up for AR is possible with a PC and a USB camera (we revisit the minimal system set-up issue in Section 3.2). However, the most distinctive feature of AR systems is that it provides direct tangible 3D interaction with the virtual objects, thus presents a cost effective way to provide the “hands-on” feeling.

Despite such projected benefits of AR based contents, there are not many studies that have validated their educational effects. In addition, we have found out that while the application of VR or 3D interactive graphics to education seems natural even to very young children (due to their exposure to 3D games), AR based contents are very surprising, thus draws great interest and curiosity (at least for now). Thus it is important to separate the novelty effect from the true prospective benefit of AR based contents in terms of education.

In this paper, we present a study on this issue of whether there is, or how we can improve upon the educational effect of AR based contents over the conventional 2D based ones. We start with a small study of the educational effect and interest from a "passive" AR based contents for learning about volcanoes. Some of the findings in this study were subsequently put to use to design another AR based contents for teaching the concept of "circulation of water." In particular, where possible, we have tried to match the scientific concept (e.g. circulation to round gesture) or the required "physical" exposition (e.g. using hands to measure temperature) to direct tangible 3D manipulation in hopes of producing a lasting educational effect. To validate our approach, we have compared (still on-going) the educational effect and interests generated by this AR contents over the conventional 2D interfaces (keyboard and mouse).

2. Related Work

There have been numerous VR or AR systems and contents that were applied in the context of education. Researchers at the Electronic Visualization Laboratory of the University of Illinois, Chicago have been icago hin this area developing various CAVE based VR applications for educational purposes [2][3][4]. Likewise, Billinghurst and his colleagues at the HITLab, New Zealand have developed seveelopAR based educational contents including the eyeMagicBook [2][Volcano and the MagiPlanet [5][6][7]. Shelton reviewed different AR projects in education and observed that manipulation of spatial objects leading to the advanced spatial awareness formed the basis of learning [8].

However, there is still not much enough research that clearly showing a definite advantage of VR or AR based contents over for instance the 2D counterparts. This is one reason for the educator's hesitance in terms of investing in the VR/AR technologies. But it is operationally very difficult to verify educational effects (rounding the right subject groups and dealing with young children, etc.).

Various types of 3D tangible user interfaces in the context of AR have been developed. The most typical case is the through use of marked props which act as a surrogate for the virtual objects. The virtual objects may be statically bound to strategically-shaped special props [9] or dynamically bound on a "selection" or "tool" prop [10]. Researchers also have tried to directly track and use the user's hand for more direct interaction (instead of the marked prop). This way the virtual objects can be tangibly selected and manipulated [11]. To invoke further functionalities from a selected object, simple motion gestures [12], virtual buttons [13], and location-based methods (placing the virtual object in designated locations) have been suggested [14].

3. Preliminary Study

3.1 Experiment

As a preliminary study, we have carried out a large scale experiment with young children assessing educational effect of using (individually) an AR based contents compared to the usual "lecture" style classroom situation. With permission, we have used the AR Volcano developed by Billinghurst et al. [15] . In the experiment, AR Volcano provided scientific illustrations and animations related to the volcanoes and their origin (e.g. different types of volcanoes, view of the earth's interior, etc.) registered to flat markers holdable in one hand (See Figure 1).

▶▶ **Figure 1. AR Volcano as used in the experiment.**

Table 1. Three experimental groups in the preliminary study.

No.	Group	Explanation
1	Lecture with First hand AR Experience	10 min. lecture and first hand AR experience for 5 min.
2	Lecture with AR Demonstration	10 min. lecture and AR demonstration on a large projection screen
3	Lecture only	20 min. lecture only

Table 1 describes the three subject groups tested in the study. The Group 3 was given 20 minutes of (detailed) lecture along with a Powerpoint slides and the Group 2, 10 minutes of (less detailed) lecture with 10 minutes of AR demonstration by the instructor (the slides and AR demonstration were shown on a large projection screen). The Group 1 listened to the same "less detailed" lecture for 10 minutes and used the AR contents first hand for about 5 minutes as shown in Figure 1. Note that we attached the camera on a hat worn by the user and had the user look at the monitor in the front rather than using an HMD. This was intentional as to reflect the ordinary classroom situation not equipped with HMD's.

A total of 183 students of age between 9 and 12 participated in the study and the experiment was carried out as a between-subjects study (90 students for Group 1, 51 for group 2 and 42 for Group 3). All subjects had to take a short quiz/questionnaire. The quiz asked 7 questions about the lecture (See Table 2), and the questionnaire asked about the subject feeling towards the interface. Table 3 shows the complete questionnaire (translated in English).

The subject participated in the study unknowingly (i.e. the instruction session was given like a normal science class). Thus the experiment could not be tightly controlled in terms of subject's prior knowledge (about volcanoes) or experience (with computers, 3D games), their age, keeping the exact duration of the lecture or using the AR system, making sure that the subjects are paying attention and doing their best, etc. Despite to these factors, we hope that the analysis results are valid due to the relatively high number of subjects.

Table 2. Samples of the quiz used in the preliminary experiment.

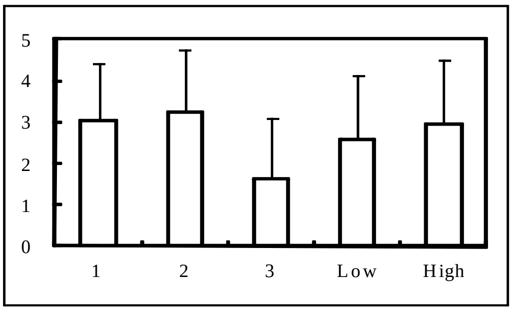
No.	Quiz Description
1-2	Give the names of parts indicated by the arrows (There is a picture with arrows directed at the "core" and the "mantle" of the earth).
3	Here are descriptions about the "mantle." Pick the right answer (There are four descriptions to choose from).
4-5	Fill in the blank. The outer crust of the earth moves because of ( ). ( ) is the melted by the heat of the earth and erupted through the volcanoes.

Table 3. The subjective questionnaire in the preliminary experiment (asked as binary O/X question).

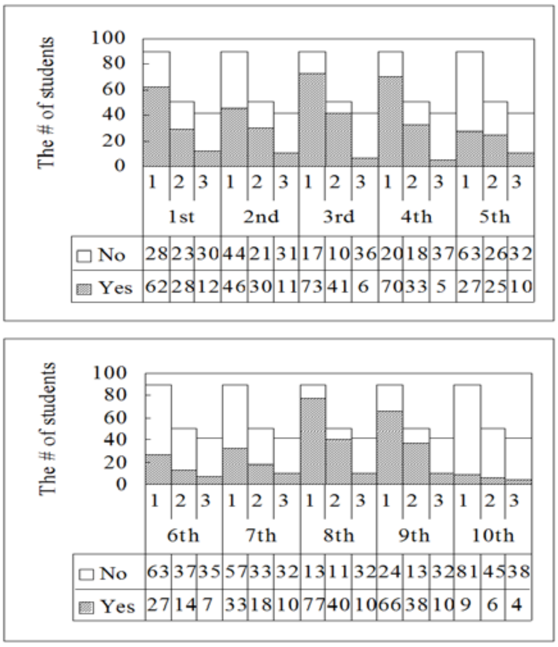
No.	Quiz Description
1	More interesting than books or internet
2	Felt as if volcano was hot like real one
3	Could see more detail
4	Felt like volcano on my hand
5	Similar to learning through web
6	Similar to playing a game
7	Same as reading a book
8	Felt like I could learn better
9	Wish to learn others subjects like this
10	Felt no interest / This is no good

3.2 Results

Figure 2 and 3 show the analysis results of the data collected from the 183 subjects. The Tukey-Kramer tests shows in Figure 2 that the Group 1 and 2, and students of higher age scored significantly higher (with p-values all less than 0.01) than the Group 3 (Lecture only). Figure 3 shows the percentages of the binary answers for the 10 questions of Table 3 (all results significant with p-value less than 0.05 except for No. 6, 7, and 10). In general, it could be concluded that the AR based content did draw lots of attention from the subjects and subjects felt they could learn better by direct tangible 3D user interfaces.



▶▶ Figure 2. The means and standard deviation of the numbers of correctly answered questions. The results of the Tukey-Kramer multiple comparison tests indicate all differences significant with p-value less than 0.01.



▶▶ Figure 3. The frequencies of the students answering O/X to questions 1~10. The Chi-square tests indicate differences significant except for Question 6, 7, and 10.

3.3 Ramification

However, there was not so much difference between the Group 1 and 2 in which the difference was in whether the AR demonstration was simply shown or done first hand by the subjects. This was a clear indication that for AR based contents to succeed it would have to include interaction. The AR Volcano did not have any interaction other than the user being able to hold and manipulate the virtual objects on one's hand. The users were not able to invoke any further interactive behavior.

We also observed that many subjects attempted to interact with the virtual object anyway. For instance, a subject would try to rotate the virtual earth, not by rotating the marker itself, but by using the other hand to rotate the earth directly, or feeling the top of the volcano or trying to insert one's hand into the volcano to see if it is actually hot! This reconfirmed our projection that the direct tangible 3D interaction would be the key element in making an AR based content successful by strengthening the proprioceptive and tangible senses as tied to the education material.

We also worried about the usability of the AR system as deployed in the study without an HMD. Without the HMD, the major projected difficulty was with the inconsistency between the line of sight and place of interaction (that is, the user is looking at a display in front, while the actual interaction occurring at one's hands). Most subjects were able to adjust to this situation in the matter of 10's of seconds. However, no quantitative data were collected for this.

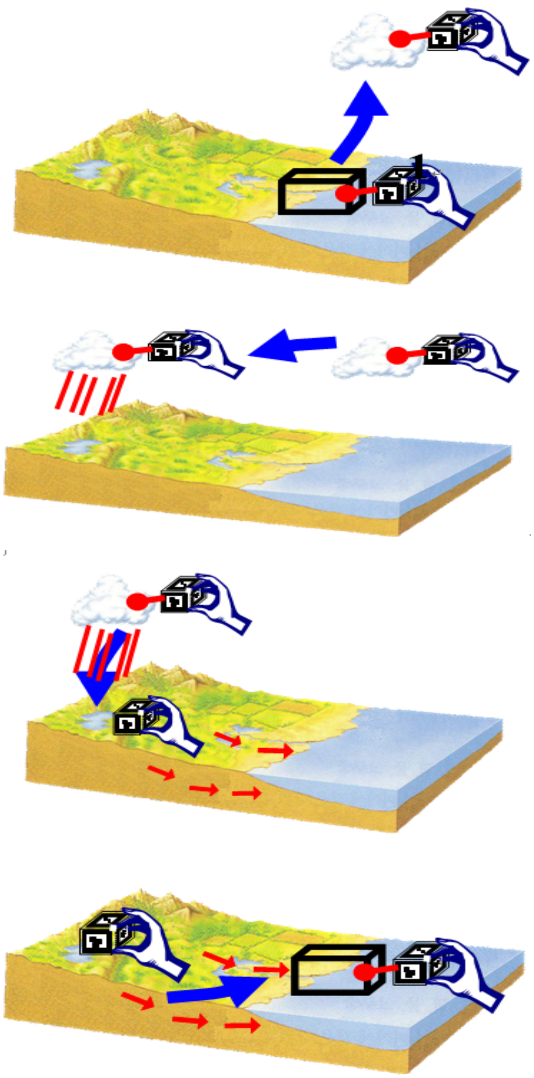
4. Contents Design: Interactive AR

4.1 Scenario: "Circulation of Water"

Figure 4 shows the overall scenario of the new interactive AR content designed for the educational theme of "circulation of water." The content revolves around four scenes each depicting a "macro" phase in the circulation of water and these phases are advanced by user interaction. From the "macro" phases, users are able to enter, interact and experience the "micro" world (e.g. explaining how a cloud is formed). In the subsequent subsections, we describe how we designed these interactions. Note that interactions for simple logical commands (e.g. "go to previous scene") need not AR based interactions and can be just carried out using the keyboard or mouse.

4.2 Circulating through the phases

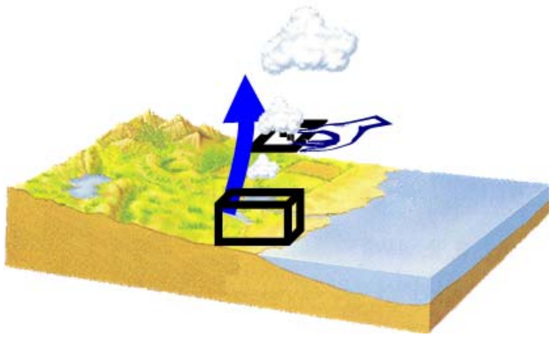
In order to associate the concept of “circulation” to student’s proprioception through physical motion, a circular gesture was chosen as the way to have the user move through the macro states. As shown in Figure 4, a cube shaped prop is used to track the movement of the hand and specific objects (e.g. a group of vapor, cloud, rain cloud, lake) are selected to induce a circular path (and gesture) within the environment to invoke the phase changes.



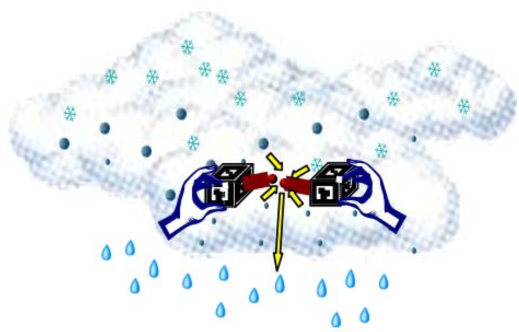
▶▶ Figure 4. The four “macro” states of the circulation of water (initial → evaporation and formation of clouds → rain → water flows in the land). Moving through the “macro” states of the circulation of water is done by a circular gesture.

4.3 Cloud Forming and Atmospheric Height

The third “micro” world interaction has to do with the formation of the cloud. This is related to the interaction described in the previous subsection, but at the “cloud” level rather than at the “water particle” level. As clouds start to form at high atmosphere with low temperature, the same “height” is associated with the physical interaction. Plus differently to the previous interaction, we make it such that the user must hold the marker (rather than the prop) on one’s palm and move it upward to observe the evaporated water turn slowly into clouds and vice versa (See Figure 5).



▶▶ Figure 5. Cloud formation in one’ s hand.



▶▶ Figure 6. The rainmaker interface. The user must wait until the proper molecules attach to the either props in both hands to make the combination happen and make a rain drop fall.

4.4 Rain Formation

The final “micro” world interaction illustrates the formation of rain. Water particles in the cloud combine with the coagulants, and in doing so become heavy enough to drop down as rain (or snow if it is cold). The interaction was designed to experience this molecular combination first hand. The user holds two props in both hands. Molecules of either water or coagulants get attached to these props in a random fashion. The user can attempt to combine whatever is attached to the props (by bringing the props close together). If one happened to be water molecules and the other coagulants, the combination succeeds and a rain drop is formed and fallen (animation). Otherwise, nothing happens and the user can deselect the attached molecules (by simple "throw" motion) and wait for the next attachment. Figure 6 illustrates the interaction process.

▶▶ Figure 7. Snapshots from the "Circulation of Water" AR contents.

4.5 Implementation

The system was implemented using ARToolkit and OpenSceneGraph [16]. Thanks to the high extensibility of OpenSceneGraph, we could easily combine ARToolkit functions with the OpenSceneGraph library. We extended some classes of OpenSceneGraph to integrate mapping texture onto the background using a video stream and tracking transformation of AR markers. Figure 7 shows some snapshots of the AR contents.

The system was successfully exhibited at a recent APEC 2005 IT Fair held in Busan, Korea, and received very favorable response (see Figure 8). In addition it has been put to use by actual elementary school children and a usability and educational effect assessment is now on-going.

▶▶ Figure 8. Exhibition at APEC 2005 IT Fair in Busan.

5. Conclusion

In this paper, we have argued how AR based interaction would be beneficial for educational purposes to provide the "hands-on" experience. Hand's on experience is expected to be particularly useful for studies that require some level of exploration rather than rote learning. Based on our findings with the use of rather passive AR Volcano, we have designed an interactive AR contents for the "circulation of water," and tried to associate as much proprioceptive senses to the concept the contents is trying to convey to the children. We believe our experience will be valuable to other people who are attempting to apply AR or VR contents to education. The resulting content is being tested in real classrooms for its usability and educational effects.

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