Using Inquiry-based Augmented Reality Tool to Explore Chemistry Micro Worlds

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Abstract: The comprehension of micro worlds has always been the emphasis and difficulty in chemistry learning. Junior High School students' ability of imagination is not complete and mature. As a result, at the beginning stage of chemistry learning, they are not able to visualize microstructures correctly. The research targeted at the chapter "The composition of substances", and further designed and developed a set of inquiry-based Augmented Reality learning tool. Students could control, combine and interact with the 3D model of micro particles using markers, and conduct a series of inquiry-based experiments. The AR tool developed was tested in practice at Meishan Junior High School, Shenzhen, China. Through data analysis and discussion, we conclude that, a) The AR tool has significant supplemental learning effect as a computer-assisted learning tool. b) The AR tool works better for low-achieving students than high-achieving ones. c) Students generally have a positive attitude towards this software. d) Boys like this software more than girls. e) Students' learning attitude has a positive correlation with their evaluation of the software.

Keywords: Augmented Reality, chemistry learning, inquiry-based learning

1. Introduction

It is the first time that students came into the world of chemistry in junior high school. Abstract concepts such as molecule, atom, amount-of-substance, etc., are all formidable tasks for them, and they are often required to envision across micro and macro worlds, which can be really challenging. "The composition of substances" is a critical concept in chemistry learning, as it is the foundation of further learning of chemicals and organic chemistry. However, young students' ability of imagination is limited, and it is difficult for them to imagine how particles such as atoms could compose substances. The situation calls for an urge to improve the present learning methods and tools in chemistry teaching.

Augmented Reality (AR) is the extension of Virtual Reality (VR). Different from traditional VR, AR provides a seamless interface for users, which combines both the real world and the virtual world. Users can interact with virtual objects that are interposed on real scene around them, and obtain the most natural and genuine Human-Computer Interaction experience. Only a computer and a camera are needed to construct a local AR environment. The camera detects markers within its vision and then presents the real scene it captures and the corresponding virtual objects represented by the markers at the same time on the computer screen. Users could move the markers to interact with the virtual objects interposed. The New Media Consortium has predicted in its 3 years' Horizon Report from 2010-2012 that Augmented Reality will be applied in large scale in the near future.

With the rapid development of Augmented Reality, the integration of AR with disciplinary teaching has greatly emerged. There are two cases where AR is most applicable, a) When the phenomenon cannot be simulated in reality, for example, the solar system in "the book of the futures" (Cai, Wang, Gao, &Yu, 2012); b) When real experiments exist conspicuous shortcomings, for example, the convex imaging experiment (Cai, Chiang, & Wang, 2012), as keeping the candle always lit is dangerous in class.

With a review of the related computer-assisted tools in chemistry education, we consider AR is the most suitable and appropriate solution for the present problems we're faced with in the instruction of chemistry micro worlds. In this paper, we will first review related works in section 2, and then introduce the inquiry-based AR tool we developed in section 3; we further present the empirical study and results in section 4 and 5, and finally propose the conclusions in the last section.

2. Related Work

There are considerable computer-assisted learning tools in chemistry teaching, and a great number of researchers have designed specific scenarios with these tools and tested their learning effect with students. Among them, the most applauded ones in recent years for microstructure learning is Virtual Reality and Augmented Reality based learning tools.

According to Merchant et al. (2012), they examined the impact of 3D desktop virtual reality environments on learner characteristics with 3 simulations set up in Second Life. The interactive features of these applications include the ability to interact with the object by zooming in and out, rotating the object and programming the objcets to behave in a certain manner. They found that the 3D virtual reality environment would promote students' chemistry learning achievement. Dalgarno et al. (2009) used a Virtual Laboratory to prepare new university chemistry students studying at a distance for their on-campus schools. Most students who used it found it a valuable preparatory tool and would recommend it for future use. These VR applications are tested to be effective, whereas their interactive methods are considered to be unnatural and limited.

Compared with VR, AR demonstrates a more natural and innovative interactive concept, which provides students opportunities to operate. El Sayed, Zayed, & Sharawy (2011) devised an Augmented Reality Student Card (ARSC), which can represent any lesson in a 3D format that helps students to visualize different learning objects, interact with theories and deal with the information in a totally new way. The research suggests ARSC increases the visualization ability to students with minimum tools used. However, in this study only static images are rendered, some more recent researches provide more interesting and engaging interactions between students and the computer, taking full advantage of AR technology.

Iordaches, Pribeanu, & Balog (2012) implemented a chemistry scenario under the Augmented Reality Teaching Platform (ARTP). Students could fulfill tasks with colored balls on the periodic table. "Assigning semantics to a ball by placing it onto a Chemical element on the periodic table creates a feeling of freedom and control for the student who can master the learning process" (Pribeanu & Iordache, 2010). The results of the study show that by using ARTP, the students could better understand the lesson and learn Chemistry with less effort. In another study, researchers constructed an AR environment under ARIES, which allows students to conduct chemistry experiments such as the reaction of hydrochloric acid (HCl) and sodium hydroxide (NaOH) produces a table salt (NaCl) and water. "Image-based AR environments seamlessly combine interactive 3D learning content with real environments containing physical objects. The leaners can interact with the content in a direct and intuitive way by manipulation of physical objects. The active participation of learners in hands-on activities has a particularly positive effect on the perceived enjoyment, resulting in their increased motivation for learning" (Wojciechowski, Cellary, 2013).

Despite the integration of AR with science disciplines, such as chemistry and physics, AR environment also works well with art disciplines. Several recent applications of AR in art courses have proved its motivation value to students in addition to its interactive feature. Chen, & Tsai (2012) developed an augmented reality system for library instruction. The application results in significant learning performance improvement and is indeed helpful in promoting learner motivation and willingness to learn. "obviously, learners were very satisfied with the proposed ARLIS for library instruction." Serio, Ibanez, & Kloos (2012) discussed the impact of an AR system on students' motivation for a visual art course. In the paper, the authors show that augmented reality has a positive impact on the motivation of middle school students.

Our research targets at the chapter "The composition of substances" in junior high school chemistry course. Traditional 2D pictures and textbooks cause great cognitive loads on students. Using AR to learn, students can observe the molecule or crystal model from each angle. Furthermore, Piaget said that "knowledge origins from activities and recognition starts from practice". In prevalent chemistry learning software, students can only observe structures rather than interact with them. In the proposed AR environment, students could control particles in micro worlds with markers, combine molecules and substances with these particles, and further comprehend and conclude the process of substance composition.

3. Inquiry-based AR Tool Description

3.1 Instructional Design

The software contains 4 specific applications of substance composition 1) hydrogen atom and oxygen atom compose water molecule, and water molecules compose water; 2) carbon atoms compose diamond crystals; 3) carbon atoms compose graphite crystals; 4) chloridion and sodion compose NaCl.

Students are required to complete the inquiry-based activity with the AR tool and fulfill the exploration form in groups of three. We'll introduce the first learning activity (the water application) in details.

Table 1 Learning activity design of application 1.

Time	Content of the exploration form	Knowledge point
8-10 min	Learning activity 1： Operation procedure, 1.Double click application 1. 2.Put marker "4" under the camera，the atom you see is______, explain the reason________. 3.Lift marker "2" slowly, what happens _______. 4.Put maker "3"under the camera, the atom you see is______, explain the reason________. 5.Lift marker "3" slowly, what happens___ ____. 6.Put marker "2" "3" "4" on the table in order, move "2" "4" towards "3", what happens____ ____. 7.Turn marker "2" "4" to the back side, lift "3" slowly, what happens________ 8.Make a conclusion of your observation and record_______________________	Know the structure of hydrogen atom. Know the structure of oxygen atom Know the composition of atom and that electrons revolve about the nucleus. Know the composition of water molecule Know the composition of water. Able to conclude that molecule is one of the particles that could compose substances.

As shown in Table 1~~Table 1~~, after using the AR tool to complete the inquiry-based activity, researchers expect students to (1) know there are 3 particles that could compose substances, could explain the formulation of water, graphite, diamond and NaCl, know the structure of atoms of different elements, and connect the features of substances with micro structures; (2) able to generalize abstract concepts, and master basic research methods of chemistry; (3) form the habit of respecting objective facts and serious attitude towards science, inspire inner interest in learning chemistry.

3.2 Application Design

The software is programmed in Java, and the extra packages used include, NyArToolkit, Java3D and JMF (Java Media Framework). Besides accurate modeling, the essence of Human-Computer Interaction in this software is to detect and record the position of each marker in the camera's view, as the application will trigger different animation when the marker is at different position. In a word, the interaction between users and computer is position-based interaction. The following shows some operation screens of two applications, the water and the diamond case.

When students move marker "2" within the camera's view, they'll see the model of hydrogen atom as shown in Figure 1~~Figure 1~~, when lifting the marker, they'll see the electron is revolving about the nucleus irregularly as shown in Figure 2~~Figure 2~~.

Figure 1 Hydrogen Atom Model. Figure 2 The electron revolves about the nucleus

When putting all 3 markers within the view, students could see the oxygen atom and hydrogen atom as shown in Figure 3~~Figure 3~~. If both hydrogen atoms are moved close to the oxygen atom, we could see a water molecule formed as shown in Figure 4~~Figure 4~~. Afterwards, we can turn the marker of hydrogen atoms over, and lift the water molecule to observe its structure as shown in Figure 5~~Figure 5~~. When lifting the water molecule, we could see water molecules form a real water drop as shown in Figure 6~~Figure 6~~.

Figure 3 Models of three atoms. Figure 4 Three atoms form a water molecule.

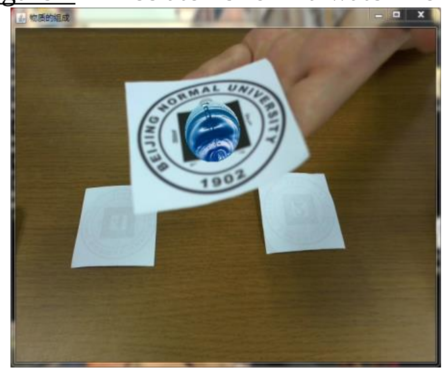

Figure 5 The structure of a water molecule Figure 6 Water molecules form a real water drop.

In the second application, the inquiry-based activity requires students to construct the diamond crystal using carbon atoms. First, we construct a basic tetrahedron unit of diamond crystal using carbon atom and chemical bond, as shown in Figure 7~~Figure 7~~. Further we will use this unit to construct a more complete structure of diamond crystal, as shown in Figure 8 ~~Figure 8~~. Students can get hints from another marker to deduct the structure they have built is the structure of diamond, which combines chemistry with daily social life.

Figure 7 Basic unit of diamond crystal

Figure 8 Part of diamond crystal

The interaction tool of this software is marker. A set contains 6 markers, with numbers printed from 1 to 6, which are selectively applicable for different applications. After the software is installed, students could use different markers to control micro particles and complete the inquiry-based learning activity as instructed in the exploration form, and further generalize concepts and conclusions.

4. Experiment Methods

The software's validity was tested in Meishan Junior High School, Shenzhen. The subjects of the empirical study are the 29 students of Class 9, Grade 2. Before the experiment, researchers installed the AR software on each computer of the classroom. The experiment design contains 4 sections as shown in Table 2~~Table 2~~.

Table 2 Experiment Design

Experiment content and operation methods	Source of measure instrument
Pre-test: a paper and pencil quiz test with every student, required to complete independently	The quiz was devised by Ms. Shengyan Wan of Meishan Junior High School.
Divide the class into groups of 3 randomly. Each group is required to use the AR tool to learn as indicated on the exploration form and complete the form in cooperation without teacher's guidance. (the tool contains AR-based software, markers and the activity form)	The exploration form is devised by the researcher, which corresponds with the software and the learning objectives.
Post-test: the same quiz test with every student, required to complete independently	The paper quiz test was the same with pre-test
Paper and pencil questionnaire survey with every student, required to complete independently	The scale consists of 4 constructs, which respectively based on the following 3 papers with minor revisions. (Learning attitude (Hwang & Chang, 2011), Satisfaction towards the software (Chu, Hwang & Tsai, 2010), Cognitive validity and accessibility (Chu, Hwang, Tsai & Tseng, 2010)).

This empirical study mainly focuses on the supplemental learning effect of AR-based learning tool. The class tested were taught the content of "The composition of substances" just in the week of this experiment. However, according to their teacher, students are not much motivated and did not comprehend the materials well, as the content is dull and abstract. Their chemistry teacher expressed the hope to review the content with AR tool. For this reason, the experiment didn't arrange a control group. The score of pre-test will represent students' learning outcome with textbooks, and the score of post-test will represent students' learning outcome with AR inquiry-based learning tool. All the tools used in the activity including the software, markers and the activity form did not literally present knowledge points in the quiz test, which means what students need to write in the quiz must be concluded by themselves in the observation and exploration during the inquiry-based learning process. And in this case, we consider the vertical change of pre-test and post-test scores will represent the AR tool's learning effect. The questionnaire mainly surveys students' attitudes towards this AR learning tool.

a. Grouping and start the applications. b. Students are learning with AR.

c. Students are cooperating in groups d. Students are answering the quiz test

Figure 9 Experiment scenes.

5. Data Analysis

5.1 Learning effect

The experiment receives 29*2 copies of quiz tests (29 for pre-test, and 29 for post-test), all considered effective. The full mark of the quiz is 32 points. We did paired t-test with the pre-test and post-test score variables. The result is shown in Table 3~~Table 3~~.

Table 3 Paired t-test of pre-test and post-test score variables

	Paired Differences					t	df	Sig (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
post-test score - pre-test score	3.310	4.115	.764	1.745	4.876	4.332	28	.000

Table 3~~Table 3~~ shows that the Sig (2-tailed) value is close to zero. When the significance level is 0.05, we should decline the original hypothesis, which suggests students' score after using AR inquiry-based learning tool has significant promotion compared with that before the learning activity. As a result, we conclude the learning effect of this AR tool is significant.

Put all students' pre-test scores in a high-to-low order, we take the first 30% as high-achieving students and the last 30% as low achieving students. Then, we conduct an independent t-test with high achieving students' learning gains and low achieving students' learning gains, as shown in Table 4~~Table 4~~.

Table 4 Independent t-test.

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig	t	df	Sig (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances assumed	2.652	.120	-2.302	19	.033	-4.218	1.832	-8.053	-.384
Equal variances not assumed			-2.383	13.908	.032	-4.218	1.770	-8.018	-.419

As the two sampling group doesn't have significant difference in variance, we should consult the upper row. When the significance level is 0.05, we consider the mean value of the two variables has significant difference. It suggests that the learning gains of low-achieving students are higher than that of high-achieving students.

5.2 *Attitudes towards the AR tool*

In this questionnaire survey, 29 copies of questionnaire were given out and 29 received, which are all considered valid. The response rate and valid rate are both 100%. The questionnaire takes Likert Scale, 6 options are set, 1 to 6 represents from "Strongly Disagree" to "Strongly Agree". The questionnaire consists of 4 constructs. We did reliability analysis of each construct, the result is shown in Table 5~~Table 5~~. As the coefficient of Cronbach's Alpha for each construct is above 0.70, we consider each construct has a high inner consistency and reliability.

Table 5 Cronbach's Alpha for each construct.

Variable	Number of Items	Cronbach's Alpha
Learning Attitude	7	0.822
Satisfaction	14	0.963
Cognitive Validity	5	0.965
Cognitive Accessibility	4	0.911

Then we calculated the score of each construct by averaging all the corresponding questions within each construct, the descriptive statistics observed is shown in Table 6~~Table 6~~.

Table 6 Questionnaire descriptive statistics of the 4 constructs.

Variable	Sample Size	Max	Min	Mean	Std. Deviation
Learning Attitude	29	3	6	4.9655	0.90565
Satisfaction	29	1	6	4.4138	1.45202
Cognitive Validity	29	1	6	4.4138	1.57020
Cognitive Accessibility	29	1	6	4.2759	1.53289

The table shows that students generally have a positive learning attitude, and present positive evaluations towards the software. Among the 4 variables, the cognitive accessibility of the learning tool acquires the minimum value.

We further compared attitudes of boys and girls. The analysis shows that boys tend to be more positive towards this AR tool than girls, as shown in Table 7~~Table 7~~.

Table 7 Comparison of attitudes of boys and girls

Variable	Sex	Mean Value	Frequency	Std. Deviation
Learning	Male	5.0556	18	0.87260
Attitude	Female	4.9655	11	0.98165
Satisfaction	Male	4.6667	18	1.28338
	Female	4.0000	11	1.67332
Cognitive	Male	4.6111	18	1.50054
Validity	Female	4.0909	11	1.70027
Cognitive	Male	4.3889	18	1.53925
Accessibility	Female	4.0909	11	1.57826

The study then analyzed the correlation between students' learning attitude and their evaluation of the AR tool. The statistics shows that learning attitude has a significant positive correlation with students' satisfaction of the AR tool, and students' evaluation of the AR tool's cognitive validity and accessibility. In other words, the more important a student thinks learning chemistry is, the more useful and satisfactory he will find the AR tool is, which is consistent with our expectations.

5.3 Observation and interview

During the process of the whole experiment, researchers observed carefully and made records of students' performance. Most students looked excited, curious and motivated during the inquiry-based learning activity. The first 2 groups to finish the whole activity were all boys. At first, 2 girls did not participate in the learning activity, meanwhile, they were doing homework on the other side; after the teacher's encouragement, they joined the experiment later. We found that most students do not like to consult the papery activity form; on the other hand, they like to interact with the software on their own. According to the responses of the activity form, we found there are still conspicuous mistakes which can be avoided with careful observation and proper teacher guidance.

After the experiment, we picked 5 students tested randomly for interview and communication. In the interview, we asked them to talk about their feelings about the learning tool. First, they admitted the AR tool could help them remember the structure of atoms. In traditional class, it's difficult to remember all these with merely teacher's plain instruction. On the contrary, the software is more attractive which leaves a deeper impression in their mind. Second, compared with previous flash courseware and other 3D modeling software, AR tool could help them develop their operation capabilities. The natural and direct interaction is better than keyboard and mouse interaction for them to remember especially the procedural knowledge. At the same time, students also proposed some suggestions towards this tool. First, the model can be instable and twinkling at times. Second, they hope the simulation of substances can be more real. Third, they hope the software could add some cartoon or animation elements to be more fascinating. When the researcher asked the 5 students interviewed whether they would like to use AR tool in future study, they said "yes" with one accord.

6. Conclusions and discussion

6.1 Preliminary conclusions

Based on data analysis of learning effect, students' attitudes, observations and interviews. We acquired the preliminary conclusions as follows,

1. The AR inquiry-based learning tool has significant supplemental learning effects.
2. The AR tool results in more significant learning gains for low-achieving students than high-achieving students.

3. Students in general possess a positive learning attitude, and present positive evaluations towards the AR tool.
4. Boys are more satisfied with the AR tool.
5. There exists significant positive correlation between students' learning attitudes with their evaluation of the AR tool.

6.2 Explanation, discussion and deduction

The empirical study belongs to software supplemental effect tests. We represent the score of pre-test as students' learning outcome with textbooks. Although students learned the chapter in class within a week, memory decay is inevitable. As a result, the score of pre-test should be lower than students' learning outcome with textbooks. We didn't arrange control group experiments, and we have to admit if they review the same content with other tools or materials, score promotion may also be witnessed.

The AR tool works better for low-achieving students, and we analyzed the possible reasons, first, the original scores of high-achieving students are very high, some even close to full mark. The promotion space is quite limited. Second, the quiz test was relatively basic, which was already mastered by high-achieving students at the start point. Third, the AR tool aims to help students explore and generalize concepts; its effect may not be entirely manifested in a paper pencil test.

Besides, representing learning gains with the score difference of paper pencil tests can be biased. With further analysis of the quiz test, we found that students' attitude towards the test is not consistent. Some students gave the right answer in the pre-test, while made clerical mistakes in the post-test. Additionally, AR tool provides a new cognitive method and expects to result in long-time memory through students' inquiry-based observation and operation. However, the post-test was conducted immediately after the learning activity, the time effect of the AR tool can not be measured.

Several groups made conspicuous mistakes in the activity form due to careless observation. On the one hand, students are required to explore by themselves without teachers guidance, their wrong operations and lack of feedback might account for this. On the other hand, we noticed in the experiment that most students didn't like to consult the operation procedures on the papery activity form. The reason might be young children prefer images than texts. When letters and pictures are presented at the same time, they may only focus on the computer screen and ignore the activity form.

To explain why boys like the AR tool better, we think it's because boys prefer operations, such as doing experiments, constructing models. Sex difference and social factors lead to that boys are more active and girls are quieter. The AR tool requires students to move markers to complete the chemistry experiments in micro worlds, and it's obvious that boys have advantages over girls.

The last conclusion, which suggests there is a correlation between students learning attitudes and their evaluation of the AR tool indicates that AR tool is like any other learning tool, the learning gains it may bring is based on the fact that students feel learning the discipline is important. If researchers want to promote this AR tool, the primary task is to promote students' learning initiative, and let them genuinely consider learning chemistry is important and rewarding.

In both the interview and the questionnaire, we found that students think the stability of the AR tool is not satisfactory. The main reason is AR software needs to detect the real scene with the camera, which can be constricted by the lighting condition of the spot. The problem provides more space for our improvement of the software.

6.3 Deficiencies and possible improvement

Through the empirical study, we have witnessed the great potential and acceptance of the inquiry-based AR tool, at the same time, we also discovered several aspects for the reserach to be improved and continued.

In software design,

• Promote the cognitive accessibility of the software, make it more stable and easier to use.

• Present vocal operation procedures in the software rather than texts in the activity form.

• Survey target students for their preferences, especially girls. Add elements which might attract them in the software, such as cartoon and animation.

In experiment design,

• Add a control group, which learn the same content through textbooks, and further analyze the difference between this group and the experiment group using AR tool.

• In the inquiry-based learning activity, bring in teacher’s guidance, and enable students to explore and learn under teacher’s proper instruction and feedback.

• Promote the difficulty level of pre-test and post-test. Change the structure of the quiz, avoid that all blanks examine cognitive knowledge point, and add some problem-solving topic questions.

• Conduct 2 post-tests. Launch the first post-test immediately after using AR tool, and the other a week after using it. Try to measure the long-time learning effect of AR tool.

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