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A case study of Augmented Reality simulation system application in a chemistry course

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ABSTRACT

The comprehension of micro-worlds has always been the focus and the challenge of chemistry learning. Junior high school students' imaginative abilities are not yet mature. As a result, they are not able to visualize microstructures correctly during the beginning stage of chemistry learning. This study targeted "the composition of substances" segment of junior high school chemistry classes and, furthermore, involved the design and development of a set of inquiry-based Augmented Reality learning tools. Students could control, combine and interact with a 3D model of micro-particles using markers and conduct a series of inquiry-based experiments. The AR tool was tested in practice at a junior high school in Shenzhen, China. Through data analysis and discussion, we conclude that (a) the AR tool has a significant supplemental learning effect as a computer-assisted learning tool; (b) the AR tool is more effective for low-achieving students than high-achieving ones; (c) students generally have positive attitudes toward this software; and (d) students' learning attitudes are positively correlated with their evaluation of the software.

1. Introduction

For many learners across the world, chemistry is introduced for the first time in junior high school. Abstract concepts such as molecules, atoms, and amount-of-substance are formidable to junior high school students; these students are often required to envision across micro- and macro-worlds, which can be extremely challenging. "The composition of substances" is a critical concept in chemistry learning, as it is the foundation of further learning about chemicals and organic chemistry. However, young students' imaginative abilities are limited, and it is difficult for them to imagine how particles such as atoms compose substances. This problem necessitates improvement in the learning methods and tools used in chemistry teaching.

Augmented Reality (AR) is an extension of Virtual Reality (VR). By contrast to traditional VR, AR provides a seamless interface for users that combines both the real world and the virtual world. Users can interact with virtual objects that are interposed on real scenes 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 scene it captures and the corresponding virtual objects represented by the markers simultaneously on the computer screen. Users can move the markers to interact with the interposed virtual objects. In the three Horizon Reports released during 2010–2012, the New Media Consortium predicted that Augmented Reality will be applied on a large scale in the near future (Johnson, Adams, & Cummins, 2012; Johnson, Levine, Smith, & Stone, 2010; Johnson, Smith, Willis, Levine, & Haywood, 2011).

With the rapid development of Augmented Reality, the integration of AR into disciplinary teaching has emerged to a significant extent. AR is most applicable in the following two cases: (1) When the phenomenon cannot be simulated in reality, such as the solar system in "the book of the futures" (Cai, Wang, Gao, & Yu, 2012). (2) When real experiments have conspicuous shortcomings, such as the convex imaging experiment (Cai, Chiang, & Wang, 2013), as it is dangerous to keep a lighted candle in a classroom. Another example is a serious game for the treatment for a 25-year-old woman with cockroach phobia through a mobile phone (Botella et al., 2011). The use of the game reduced her level of fear and

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avoidance before a "one-session" AR exposure treatment was applied.

After a review of the related computer-assisted tools in chemistry education, we consider AR the most suitable and appropriate solution for the present problems we are faced with in instruction on chemistry micro-worlds, as micro-particles cannot be observed in reality.

This research aims to develop an inquiry-based AR learning tool for junior high school chemistry courses, examine its effect on students' cognitive performance, compare its effects on high-achieving and low-achieving students and investigate students' attitudes toward the software.

2. Literature review

Spatial ability plays an important role in chemistry learning, as students are required to visualize specific microstructures, but the visualization of microstructures is a difficult task for students. According to Harle and Towns (2011), research that has focused on visuospatial skills in chemistry has uncovered specific student difficulties in comprehending, interpreting, and translating molecular representations. The study of Tuckey, Selvaratnam, and Bradley (1991) indicated that even at the university level, many students have difficulties with three-dimensional thinking. These difficulties are caused by a misunderstanding of merely a few relatively simple concepts and skills. Sorby (2009) concluded that the implementation of a course aimed toward the development of the 3D spatial skills of first-year engineering students, it appears to have had a positive impact on student success, especially women. This result suggests that spatial skills can be improved through practice and may result in better academic performance. Based on these studies, we aim to eliminate the difficulties faced in chemistry microstructure instruction with regard to spatial skills.

A considerable number of computer-assisted learning tools are used in chemistry teaching, and a great number of researchers have designed specific scenarios using these tools and tested their learning effect on students. In recent years, the most highly praised of these tools for microstructure learning are Virtual Reality- and Augmented Reality-based learning tools.

Dalgarno, Bishop, and Adlong (2009) used a Virtual Laboratory to prepare new university chemistry students through distance learning. Most students found it to be a valuable preparatory tool and would recommend it for future use. These VR applications have been determined to be effective, whereas interactive VR methods are considered unnatural and limited. Merchant et al. (2012) examined the impact of 3D desktop Virtual Reality environments on learner characteristics using three Second Life simulations. The interactive features of these applications include the ability to interact with an object by zooming in and out, rotating the object and programming the object to behave in a certain manner. They found that the 3D virtual environment would promote student chemistry learning. In the work of Stull, Barrett, and Hegarty (2013), they examined the perceptual differences between using virtual and concrete model to learn organic chemistry. The learning task includes matching and comparing molecule structure and diagrams. It's discovered that there is no difference in the accuracy of task completion using two models, but virtual model provides a higher efficiency.

Compared with VR, AR demonstrates a more natural and innovative interactive concept, which provides students with opportunities to perform. El Sayed, Zayed, and Sharawy (2011) devised an Augmented Reality Student Card (ARSC), which can represent any lesson in a 3D format that aids students in visualizing different learning objects, interact with theories and manage information in a totally new way. The research suggests that ARSCs increase students' visualization abilities using a minimum number of tools. Nunez, Quiros, Nunez, Carda, and Camahort (2008) presented an AR system for teaching spatial relationships and chemical problems with university-level students. In the experiment, students could manipulate crystal structures of certain substances, such as $ZrSiO_4$ with markers. However, in the studies above, only static images or structures are rendered. Some more recent studies indicate more interesting and engaging interactions between students and the computer, taking full advantage of AR technology.

An Augmented Reality Teaching Platform (ARTP) in chemistry was proposed in Iordache, Pribeanu, and Balog (2012). A periodic table is provided where students could place colored balls to complete tasks. The researcher found the activity of placing colored balls onto different chemical elements on the table give the children the feeling of freedom and control, which is beneficial for their mastery. The results show that students understand more comprehensively and easily with this tool. Wojciechowski and Cellary (2013) constructed an AR environment in which students could conduct chemistry experiments, for example, hydrochloric acid (HCl) and sodium hydroxide (NaOH) react producing table salt (NaCl) and water. The results show that "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", as such seamless AR environments combine learning materials and the real scene around students, providing them with opportunities to manipulate the objects on their own.

In Mayer's multimedia learning theories research, he presented seven principles to involve animation in multimedia learning, the first principle is that students learn deeply from narration and animation than narration alone (Mayer & Moreno, 2002). Guided by this, in the AR application, we seamlessly incorporate interactive animation into the learning scenario.

Besides science disciplines, the AR environment also works well with art disciplines. An AR system for library instruction was developed, which resulted in significant learning performance improvement and was indeed helpful in promoting learner motivation and willingness to learn. "Obviously, learners were very satisfied with the proposed ARLIS for library instruction." (Chen & Tsai, 2012). In a visual art course, Di Serio, Ibáñez, and Kloos (2013) discussed the impact exerted by an AR system on students' motivation, which showed that AR has a positive impact on the motivation of middle school students. Fonseca et al. (2014) offered an opportunity to visualize different stages of a constructive process by AR on mobile devices, in order to improve the understanding of the process and to investigate the relationship among the usability of the tool, students' participation, academic performance after using AR. The results pointed out that the use of mobile devices in the classroom as well as motivation and academic achievement are highly correlated.

Our research targets "The composition of substances" segment of junior high school chemistry syllabus, which requires instruction in microstructures. Considering the difficulty that may exist in the teaching of these abstract materials and the important role that spatial ability plays in molecular geometry learning, we choose to develop an AR-based learning tool. Traditional 2D pictures and textbooks place great cognitive loads on students. Using AR to learn, students can observe a molecule or crystal model from each angle. Furthermore, Piaget (1972) said that "knowledge originates from activities and recognition starts from practice". With prevalent chemistry learning software, students can only observe structures instead of interacting with them. In the proposed AR environment, students can control particles in micro-worlds with markers, construct molecules and substances with these particles and, furthermore, comprehend and conclude the process of substance composition.