Full immersive virtual environment CAVE™ in chemistry education

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Abstract

By comparing two-dimensional (2D) chemical animations designed for computer’s desktop with three-dimensional (3D) chemical animations designed for the full immersive virtual reality environment CAVE™ we studied how virtual reality environments could raise student’s interest and motivation for learning. By using the 3ds max™, we can visualize the chemical phenomena easily and quickly without knowing any special computer language and export the application to files which are compatible with the CAVE™ (Object or OpenGL files). After the participation in 3D animations at the CAVE™ students comprehended the molecules’ structure and their changes during a chemical reaction better than during the 2D animations on the computer’s desktop, as the limitations of human vision had been overcome. Furthermore, the students were enthusiastic, as they had the feeling that they were inside the chemical reactions and they were facing the 3D molecules as if they were real objects front of them.

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1. Virtual reality environments-CAVE™

In the last decade, virtual reality environments in which the user has the feeling of being present in systematic environment have emerged. virtual reality (VR) incorporates high-speed three-dimensional graphics, audio feedback, psychology and special peripheral devices to produce “realistic” computer generated interactive environments that are indistinguishable from reality. The display devices which are used in the virtual reality environments are characterized by the level of immersion in the synthetic environment, the techniques of immersion and the number of users who can participate in it (Fernades, Raja, & Eyre, 2003). Types of virtual reality (VR) technology include (Neale & Nichols, 2001):
Desktop systems, where the virtual environment is displayed on a conventional computer monitor and the interaction is achieved by either traditional input devices such as mouse and keyboard. Although this type of virtual reality technology does not give the feeling of the full immersive environment to the users, its cost is lower than the stereoscopic displays.

Stereoscopic displays: They provide to the eyes of the viewer two different images, representing two perspectives of the same object, with a minor deviation similar to the perspectives that both eyes naturally receive in binocular vision. If eyestrain and distortion are to be avoided, each of the two two-dimensional (2D) images preferably should be presented to each eye of the viewer so that any object at infinite distance seen by the viewer should be perceived by that eye while it is oriented straight ahead, the viewer’s eyes being neither crossed nor diverging.

1. Immersive HMD based systems (Fig. 1), where the virtual environment is displayed via a head mounted visual display and the interaction and movement may be controlled using a tracked hand-held input device. The user wears a head set containing video displays both eyes and set of head phones. These immersive displays are not suitable for a long period of use (Lee, Cherng, & Lin, 2004).

2. Immersive project technology systems (IPT), where images are projected on surface(s) around the users. More than one user can participate in this virtual reality environment. The full immersive virtual reality environment is the CAVE™, where the participant is in a room and the virtual environment is displayed on the walls around the users (Cruz-Neira, Sandin, & DeFanti, 1993) (Fig. 2) giving them the feeling of the “real” world. The users wear stereo shutter glasses which are comprised of polarized lenses to give them the feeling of three-dimensional (3D) environment.

Cruz-Neira et al. (1993) described the CAVE technology and its configuration problems. The CAVE is a room 10 ft × 10 ft × 10 ft made up of three rear-projection screens for walls and a down-projection screen for the floor (Fig. 3). Projectors throw full-color workstation fields (1280 × 512 stereo) at 12 Hz onto the screen, giving between 2000 and 4000 linear pixel resolution to the surrounding composite image. A user’s head and hand are tracked with Polhemus or Ascension tethered electromagnetic sensors. Stereo graphics’ LCD stereo shutter glasses are used to separate the alternate fields going to the eyes. Four silicon graphics high-end workstations create the imagery (one for each screen) which is tied to a fifth for serial communications to input devices synchronization via fiber optic reflective memory. The CAVE is settling down in a 30 ft × 20 ft × 13 ft room, provided that the projectors’ optics is folded by mirrors.

The goals inspired the CAVE engineering effort include (Cruz-Neira et al., 1993):

1. The desire for higher-resolution colour images and good surround vision without geometric distortion.
2. Less sensitivity to head-rotation induced errors.
3. The ability to mix VR imagery with real devices (like one’s hand, for instance).
4. The need to guide and teach others in a reasonable way in artificial worlds.

Fig. 1. Head mounted display.
5. The desire to couple to networked supercomputers and data sources for successive refinement.

Some types of the files apart from files writing C/C++ that the CAVE™ could support are VRML, OpenGL, Object files. In these files, there are information about the 3D appearance and the behavior-actions of the 3D objects.

2. Virtual reality and learning

“Virtual environments can provide a rich, interactive, engaging educational context, supporting experimental learning” (Mantovani, 2003). Burner (1996) pointed out that VR can provide a medium to learn by doing, through first-person experience enhancing the learning procedure. First-person experiences play a central role in his/her interaction with the world. The learners construct their own reality through interpretation of personal perceptual experiences. The reality is constructed in their mind and the learners build up their personal model of reality, which they can communicate but not entirely share with other people (Jonassen, 1991). “Meaning could be constructed from information outside of learner, or could be constructed by each individual using information from the environment and from within” (Osberg, 1992). VR provides the opportunity of making first-person experiences; immersive environments allow constructing knowledge from direct experience by giving the participants the “perceptual illusion of no mediation” between them and the virtual world. VR technology provides learners with the possibility to reflect and get a deeper understanding of the process through which a person can reach knowledge of the world (Mantovani, 2003).
3. Chemistry education

“Chemistry is a conceptual subject and in order to explain many of the concepts teachers use models to describe the microscopic world and relate it to the macroscopic properties of matter (Taber, 2002)”. According to Johnstone (1997), chemistry consists of three forms which can be thought of as corners of a triangle. No form is superior to another, but each one complements the other. These forms of the subject are: (i) the macro and tangible: what can be seen, touched and smelt; (ii) the sub micro: atoms, molecules, ions and structures and (iii) the representational: symbols, formulae, equations, molarity, mathematical manipulation and graphs. Most of the things which we encounter in the world, and on which we form many of our concepts, are macro in nature. But chemistry, to be more fully understood, has to move to the sub micro where the behavior of substances is interpreted in terms of the unseen and molecular and recorded in some representational language and notation (Johnstone, 1997). However, many times there is a conflict between the chemical science and the student’s every-day experiences and use of language; as a result many misconceptions have been detected in the students’ answers and ideas about chemistry (Garratt, Horn, & Tomlinson, 2000; Huddle, White, & Rogers, 2000; Nakhleh, 1992). However, “discovery or investigative chemistry” attempts to involve students in their own learning.

4. Investigation

In our investigation we compared 2D chemical animations designed for computer’s desktop with 3D chemical animations designed for a full immersive virtual reality environment and we studied how virtual reality environments could raise student’s interest and motivation for learning and promote chemistry learning. This research was held in the Centre for virtual reality of Salford University (UK) and we presented the two different kinds of chemical animations (2D and 3D) to the same group of students of Eccles College. In their College the chemistry courses was conducted in a classroom and in a laboratory and the students were familiar with information technology, as their teacher used Power-Point presentations, educational CD-Rom and websites as educational tools. The students did not have any previous experience on the full immersive virtual reality environments such as CAVE™.

The chemical animations (2D and 3D) were developed in 3d studio max™ (3ds max™), which is a registered trademark of Autodesk, Inc. (2002 Microsoft Corporation). 3ds Max is one of the most widely-used off the shelf 3D animation programs by content creation professionals. There are a lot of books which describe the use and the design of 3ds max providing us with tutorials lessons (Murdock, 2003). By using 3ds max™ a designer can create 3D objects similar to real one and observe them from different perspectives and angles. These 3D objects can be exported as static images (jpg and bmp files) or can be exported as animation (avi, mov and png files).

Furthermore, by using the PolyTrans I/O converter plug-ins from Okino Computers Graphics for 3ds max™ (http://www.okino.com/conv/pt4max.htm) 3D objects can be exported as 3D images or animations (Object or OpenGL files) which are compatible with the CAVE™ technology.

5. Animations

The two different kinds of animations (2D and 3D) which we developed by using the 3ds max™ were about

1. the reaction of methyl orange with acid and its behavior in the water.
2. the air and the formation of acid rain.

The animations were designed following the cognitive load theory aspects which assumes that the human cognitive system consists of two distinct channels for representing and controlling knowledge: an auditory-verbal channel and a visual–pictorial channel (Mayer & Moreno, 2002) and a limited working memory can process only a few elements of current information at any given time (Gabel, 1999; Pollock, Chandler, & Sweller, 2002). Robinson (2004) has synoptically referred to the basic aspects of cognitive theory which are necessary to design a multimedia application.
In chemistry the reactions take place in solutions and the compounds that participated in it are big as a number. Following the cognitive load theory the animations were divided into two parts in order to decrease the complexity level.

5.1. Animation about methyl orange

Firstly, students observed how hydrochloric acid and methyl orange react together without the existence of water (Fig. 3). In this way they become familiar with the molecules of hydrochloric acid and methyl orange and observed the change in structure which happens when these two molecules reacted together.

After that, the students observed the same reaction but in an aqueous solution. This part was more complicated than the first, as water molecules also participated in the reaction (Fig. 4). In that animation, we used the sulfuric acid as link for the next animation which was about the formation of acid rain.

5.2. Animation about the formation of acid rain

This animation was divided into three part: (a) air (air molecules in motion), (b) formation of cloud (water accumulation) and the formation of acid rain (formation of sulfuric acid) (Fig. 5).

6. Introductory part

In order for students to have the same background when they observed the animations, we introduced them to the cognitive subject of (i) acid–base, indicators and the structure of methyl orange and (ii) the composition of air and the formation of acid-rain using Power-Point presentation. These topics were well-known to
students as they have been taught them during their studies. Thus, the students were informed about the topics and they could focus on the chemistry of 2D/3D animations knowing the theory behind them. The total presentation was around 30 min.

6.1. Experimental condition

The first part of our investigation was conducted in a classroom equipped with a Projector. The students observed the 2D animations (Figs. 3–5) which were designed for the computer’s desktop and discussed with the teacher every part of the animation. For example, the teacher described and explained the change of methyl orange indicator when it reacts with an acid. The total time of this part of the presentation was 15 min and the total number of students was 14.

The second part of this investigation was conducted in the CAVE™ and the students were divided into three-groups of five in order to participate actively at the presentation in the full immersive environment CAVE™. High resolution computer images, projectors, mirrors, stereo shutter glasses, tracking system, data glove and joystick are required in a CAVE™. A tracking system allows changes of angle and orientation of the 3D objects to be recorded and a joystick assists users to move the 3D object forward or backward or rotate it in different angles.

The teacher put on her head the tracking system in order to look around a virtual reality environment simply by moving the head without need a separate controller to change the angle of the imagery. By using a joystick, the teacher rotated the molecules, moved them closer or away from her and controlled the animations (e.g. paused it in order for the students to observe it better).

The five students of each group wore the stereo glasses and were situated in a circle around the teacher. As we have described the 3D animations were the same as the 2D animations that the students observed on the computer’s desktop but were compatible with the CAVE™. In Figs. 6 and 7 we illustrate part of the presentations in the CAVE™.

The teacher explained what happened at the molecules when they react together exploiting the capabilities of CAVE™, by using the joystick the teacher moved the molecules forward or backward and rotated them in order for students to better observe the changes that happened as she explained the chemistry behind the reactions. Many times the teacher paused or rewinded the animations as she rotated them in order for students to observe the changes of the structure’s molecules from different angles. During this presentation when the teacher posed questions the students participated very actively.

The total time for the presentation in the CAVE™ for each group was 15 min (45 min participation for the three-groups).

Fig. 6. 3D methyl orange’s animation in the CAVE™. (a) Methyl orange and (b) indicator’s acidic form.
At the end of both the two presentations, we distributed to the students multi-choice questions which included the same chemistry questions in order we to compare he students’ answers (after their participation in classroom or in CAVE™) and the end of their participation in the CAVE™ we asked them to express their impressions about the animations and the virtual reality systems.

7. Results–discussion

The aim of the chemistry questionnaire was to establish whether the students better understood the chemical topics after their participation in the full immersive virtual environment compared to the computer's desktop application. By processing the data of the correct answers (ANOVA statistic analysis) we found that there was a significant difference between the students’ answers after their participation in the classroom and the CAVE™ (Table 1). Thus, although the limitations of the human vision had been overcome with the visualisation of chemical phenomena using either the desktop or 3D animations, only by using the CAVE™ did the students feel that they were inside the chemical reaction-phenomenon and they could observe the chemical reactions from different perspectives and angles and participated actively in the teaching process, posing questions to teacher about the structure of molecules etc. Furthermore, by using desktop animations, the students did not gain a sense of the molecules in 3D and their volume in the space. However, by using a 3D application in CAVE™, it was easy for students to understand that the molecules are not flat. Furthermore, it was not necessary for the teacher to describe the location of molecules inside the solution or in the air, the way that they reacted with one another and their structure before and after the chemical reaction. Moreover, the molecules’ structure and their changes during a chemical reaction were better perceived using CAVE™ animations than on the desktop, as the students could pause the animation and they rotate it, move it forward or backward in order to observe the application better.

After participating in the CAVE™, the students expressed their opinion about 2D and 3D chemical animations and the use of the computer's desktop and CAVE™ respectively. Generally, the students assessed positively the CAVE™ animations and they believed that they understood the chemical reactions better after attending these animations on the computer’s desktop. The students were enthusiastic with the CAVE™ presentations and they pointed out that the chemical phenomena and reactions were more perceptible by using CAVE™, as they had the feeling that they were inside the chemical reaction and they could observe it from different angles. Additionally, they reported that although they knew that air consists of molecules, they did not have the sense that they were surrounded by all these molecules in their every day life. Finally, they stated that they had the opportunity to pose more questions and discuss with the teacher more interactively than during the presentation of 2D animations.

![Fig. 7. 3D acid rain’s animation. (a) Molecules in the air moved closer to the user and (b) molecules in air moved away from the user.](image)
8. Conclusion

“Chemistry is a conceptual subject and in order to explain many of the concepts teachers use models to describe the microscopic world and relate it to the macroscopic properties of matter (Taber, 2002).” However, many times there is a conflict between chemical science and the student’s everyday experience and use of language (Bradley & Brand, 1985; Garratt et al., 2000; Nakhleh, 1992; Ozkaya, Uce, & Sahin, 2003; Peterson & Treagust, 1993). The full immersive virtual reality Environment CAVE™ allows students to appreciate the molecule’s structure and the change of their structure during a chemical reaction better than applications of the computer’s desktop, as the limitations of human vision can be overcome. This issue is real important in chemistry education as the chemistry is very difficult science and request from students to realize in depth the phenomena, but many times the teacher can not transfer the knowledge to the student’s mind.

Most recently researches have been focused on molecular visualisation in order to use them both for teaching and research (Jose & Williamson, 2005; Paselk, 1994). According to Jones, Jordan, and Stilling (2005), chemical phenomena are not obvious without the use of visualisation and in order to develop them it needs the existence of visualisation tools such as molecular modelling programs and visualizing chemical phenomena.

Table 1
ANOVA analysis (α = 0.05) for the chemistry questions in order to compare the student’s answers after the classroom and the full immersive environment CAVE™

First Question (Q1): “In order to find the pH in an aquatic solution we measure the concentration of hydrogen ions which is a result of (a) the existence of indicators in the solution, (b) the reaction of acid with the base, (c) the dilution of acid in the water and (d) the pH of the solution”.

\[
F(1,26) = 9.23, \ MS_W = 0.190, \ p = 0.005 \\
\text{Desktop } (M\% = 35.71, SD\% = 49.72) \text{ – CAVE } (M\% = 85.71, SD\% = 36.31)
\]

Second Question (Q2): A typical acid–base indicator is a weak acid or base, which exhibits a relatively sudden and easily discernible colour change at a given pH (pH is the negative log of the hydrogen ion molar concentration). Methyl orange is one of the most widely-used acid–base indicators and it is a weak acid.

According to the above theory, does the methyl orange change colour, because (a) ions are formed, (b) indicator is acid, (c) only the specific part of the compound has the opportunity to share electrons with H and to attract it and (d) the structure of the compound changes”.

\[
F(1,26) = 10.44, \ MS_W = 0.168, \ p = 0.003 \\
\text{Desktop } (M\% = 42.86, SD\% = 51.36) \text{ – CAVE } (M\% = 92.86, SD\% = 26.73)
\]

Third Question (Q3): “When the methyl orange accepts H⁺ then (a) its structure changes in space in order to take H⁺ to the appropriate position, (b) there is not any different change in structure just the N attracts the H⁺, (c) the H⁺ can form a bond with any atoms (N, H, C, S) and (d) the H⁺ forms hydrogen bond with N”.

\[
F(1,26) = 19.87, \ MS_W = 0.146, \ p = 0.000 \\
\text{Desktop } (M\% = 28.57, SD\% = 46.88) \text{ – CAVE } (M\% = 92.86, SD\% = 26.73)
\]

Fourth Question (Q4): “The acid rain is formed (a) when the sulfur dioxide reacts with the water, (b) when the sulfuric trioxide is formed, (c) when molecules of water and acid react together and (d) when salt and water react together”.

\[
F(1,26) = 6.50, \ MS_W = 0.198, \ p = 0.017 \\
\text{Desktop } (M\% = 14.29, SD\% = 36.31) \text{ – CAVE } (M\% = 57.14, SD\% = 51.36)
\]

Where α is the limit of significant deviance, MS_W is the mean square correct answers after the 2D and 3D animation presentation, F(a, b) is the variance between correct answers/MS_W, p is the actual deviance, with four decimal places, Desktop the answers after the presentation in the classroom, CAVE the answers after their participation in the full immersive environment, M is mean, and SD is standard deviation.
we could link the theory with laboratory (Jones, 2001). Pictures seldom can capture all the subtle nuances of a model, but good pictures and movie clips are not only what are best remembered, they also often enable us to take the next steps in both teaching and research (Zare, 2002). However, apart from the high resolution images or animations observation, the student should get involved actively in chemistry education in order to understand the phenomena. The full immersive system allows us to create an environment in which the students can be inside the chemical reaction as if they are part of the reaction.

After participating in the full immersive system, the students were enthusiastic, as they had the feeling that they were inside the chemical reactions/the air and they could observe the molecules from different angles. The students' reactions during their participation in the CAVE™ were remarkable. They face the 3D molecules as if a real object was in front of them trying to grab them.

By using the 3ds max™, we can visualize the chemical phenomena easily and quickly without knowing any special computer language and to export the application to files which are compatible with the CAVE™ (Object or OpenGL files).

The disadvantage of the full immersive virtual reality systems is that the equipment at the moment is quite expensive for a chemistry department as it would consume a large amount of their budget to maintain and support the laboratory equipment. However, as the technology is developing, low cost immersive virtual reality environments have been emerged (Fairen, Brunet, & Techmann, 2004). Also, in recent techniques the user has the feeling that the virtual objects have weight or the user can feel attraction and repulsion by the virtual objects (haptic interaction) (Lee & Lyons, 2004; Tsafestas, Koumpouros, & Birbas, 2004). Perhaps in the near future, chemists will train in a full immersive virtual reality laboratory in order to obtain experience-skills which are difficult to obtain from a traditional education.

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