LEARNING CHEMISTRY WITH 3D VISUALIZATIONS EMPLOYING CARTOONS AGENTS IN HIGHER EDUCATION

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Abstract

Students in higher education usually find it challenging to understand and picture the particulate nature of matter in microscopic level. However, students often face difficulties in that field and how to link that knowledge to macroscopic behaviour. Therefore, the main purpose of this work is to present a specifically designed educational material that focus to the benefits of viewing visualizations to enhance students' conceptual understanding of chemistry concepts. Under this frame, educational material for specific basic chemistry concepts that are taught in the Chemistry course and supplied at the National Technical University of Athens, in which 3D visualizations with cartoons were constructed and employed. The material was designed for in class use from the educator or for core –concept use. Concepts that combine the microscopic level with the symbolic language were chosen. So, specifically 3D dimensional visualizations were made for the atomic orbitals (dxy, dxz, dzy, dz^2), types of solids - ionic structures (crystal of sodium chloride), molecular structures (water), covalent lattice structures (diamond, graphite structures), metallic structures (copper) etc. Since it was planned all constructed applications to run on all functional and most browsers in terms of 3D, so code three js (javascript that supports 3D) was used. Also, the interactive agents "cartoons" Einstein and Curie, were developed from scratch in programs that apply animation in 2D characters, giving them freedom of movement and realism at the same time. In the near future a planned research will be carried out to study and find out how the students' scientific knowledge can be reconstructed in the above mentioned concepts in the Inorganic-General Chemistry course, which is taught at three schools of the National Technical University of Athens, exploiting the developed cognitive and their metacognitive abilities, their spatial ability and their optical encoding.

Keywords: Cartoons agents, 3D visualizations, chemistry, higher education.

1 INTRODUCTION

Cartoons constitute an appealing teaching method to introduce unusual and amazing activities that could enhance learning and students' participation also in Higher Education. Cartoons have the power to draw attention and come to the specific point quickly. When they are placed in educational material that employ 3D visualizations, they provide by definition an interesting learning tool in Sciences (Chemistry), which provide opportunities for feedback against alternative ideas throughout the learning process and provide valuable information regarding the students misconceptions and how they "overtake" them.

In Science courses students must be able to visualize 3D molecular geometry shapes, understand and rebuild principles that determine spatial arrangement, and have the ability to relate how these principles a□ect spatial arrangements ([1]). 3D visualizations appeals to a challenging spatial domain area, basic for the deep understanding of Chemistry concepts related to microcosm. For instance researchers as Trevor et al. ([2]) studied systematically the effectiveness of virtual and concrete models for aligning and producing multiple representations in stereochemistry with a sample of college students without prior domain knowledge in organic chemistry. Their findings reinforce the point that 3D models are more useful than concrete models, even for spatial domains, and can actually be more effective in supporting the process of developing representational competence in science. Also Merchant et al. ([3]) examined the impact of a 3D desktop virtual reality environment on the learner characteristics (i.e. perceptual and psychological variables) that can enhance chemistry-related learning achievements in an introductory college chemistry class, and their findings were positive. They focused on a photo-realistic display of 3D molecule that can create a perception of viewing a real molecule and the students' interaction which is their ability to influence the occurrences of events in the virtual environment by their actions. This would entailed the capabilities of exploring, manipulating,

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rotating, and viewing objects from multiple perspectives as in the case of chemistry where they can rotate a molecule over 360^{o} angle to view the different angles/surfaces.

In that high demanding learning process the cartoons as a supplementary tool or as agents come to minimize the high cognitive load that students have to overcome. A basic feature of cartoons beyond the binary use of image-text and animation is that they are distinguished by humour. Humour has been shown to contribute to improving the learning process, but only under certain circumstances ([4]). The use of Cognitive Load Theory explains that these conditions are formed when humour does not burden the student's cognitive load. The problem-solving approach, commonly used in STEM education ([5]), already increases cognitive load, and the addition of humour can boost STEM education to overcome this overloading point.

The use of cartoons has a positive impact on the understanding and assimilation of the learning concepts. Ören and Meriç ([6]), through their research, concluded that the majority of students who took part in their research felt that "concept cartoons" positively motivated and redrawn their perceptions into Science and Technology lessons. Several researchers have argued that their use can help and facilitate learning teaching. They are visual representations with animation, that have been used in teaching Chemistry ([7]) and general in Sciences ([8]). They have been utilized by teachers to teach ([9]) and to evaluate students' knowledge and their level of understanding on the concepts of Sciences in all educational levels ([10], [11]).

At the San José State University, an e-learning tool (ELT) on precipitation reactions was designed and used at research level, in which a cartoons agent (chemistry teacher) “Dr. NRG " was used and directed the students of the introductory chemistry course at the college level to explore and understand the nature of the precipitation reactions ([12]). Also Kelly et al. ([13]) investigated how cartoon video tutorials featuring molecular visualizations affect students’ mental models of acetic acid and hydrochloric acid solutions and how the acids respond when tested for electrical conductance. Their research findings heightened that scaffolding animations in a cartoon context with explicit connections between experimental evidence and the submicroscopic level, resulted in students being proficient at replicating what they explicitly observed both structurally and mechanistically.

2 MULTIMEDIA EDUCATIONAL MATERIAL

Programmes have been used to build digital educational material with 2D characters (commercial and free software), giving them freedom of movement and realism at the same time as well as autonomy in their operation. The "cartoons agents" (avatar type) "digital assistants" are designed to replace the teacher by performing functions such as representing, emphasizing, highlighting, showing, describing, adding, expanding, For this purpose cartoons were constructed in the form of an avatar such as Curie and, Einstein “fig.1”, for the presentation and study of the obscure concepts of General and Inorganic Chemistry, solids with their corresponding crystal structures (microscopic level) and atomic orbitals.

Figure 1. Cartoons agents Curie and Einstein.

These concepts are difficult by definition in the level of understanding for students as they are asked to study them (at the microscopic level) to explain some physicochemical properties of solids and in the case of atomic orbitals to optimize their shapes in microscopic level regarding the formation of chemical bonds.

The pedagogical agents, which are classified as human, human-like, sound-based, text based, cartoon character- based in terms of design, are also classified as smart, assistant, informative, assessor, pedagogical, advisor and expert in terms of their functions ([14]). In our study we have chosen to create and use in the educational material cartoon characters as agents, based on the acceptance that they demonstrate by students as wel as the symbolic use of humour that they use according to literature data.

Due to the fact that we aimed to run the applications in most of the browsers, we ended up using three js and WebGl. Therefore, the construction of digital material was done in such a way that the applications run on all functional and most browsers with respect to the three-dimensional ones, resulting in their presentation in three js and simultaneously achieving the desired aesthetic level of 3D visualizations, in terms of lighting and transparency. Also added to the home page of the js code application, which recognizes the user's device automatically (tablet, computer) running and the resolution (greater or less than 800 pixels) to promote automatically the user in the version created for the device and the operating device it uses.

We have chosen to use WebGL, which is a JavaScript application programming interface (API) for rendering 3D and 2D graphics within any compatible Web browser without the use of plugins. WebGL is integrated completely into all the Web standards of the browser, allowing GPU-accelerated usage of image processing and graphic effects as part of the Web page canvas. As Yuan et al.([15]) supported that although the offline visualization tools are powerful and provide users with vivid images of macromolecular structures ([15]), they still have some obvious limitations (in biotechnology). For instance, they cannot share the visualization scene in real-time between users at different places directly. All of these tools are platform dependent, and developers have to provide various codes for installation on different operating systems. By contrast, visualization of molecule through a Web browser with WebGL ([16]) and HTML5 ([17]) technology can overcome these weaknesses. All of the data can be shared among users in different locations, and no other plugins need to be preinstalled for a Web browser ([18]).

On the other hand the digital guide / cartoon (Curie format or Einstein format) was constructed on the same screen as the three-dimensional Chemistry concepts were presented. For instance three-dimensional visualizations such as ice in forms of ball and stick "fig.2" and spacefill "fig.3" can run on top of the cartoon agents (which are enriched with the possibilities of free motion and voice recording) and overlap them .

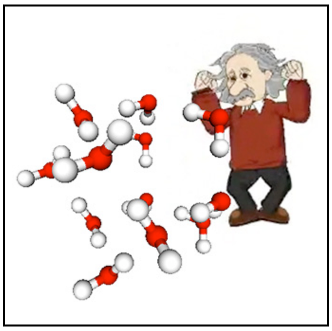

Figure 2: Ball and stick molecular model of the crystal structure of ice, where each oxygen atom in the ice structure is surrounded tetrahedral by four hydrogen atoms, two closely adjacent and covalently attached thereto, providing the water molecule, and two others located farther and are retained by hydrogen bonds.

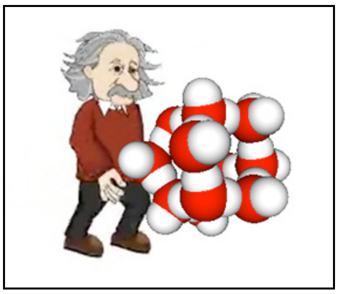

Figure3: Spacefill model of ice molecule

.It also allows the user to stop or repeat the video with the recording and movement of the cartoon "fig.4".

2.1 Examples of types of solids - ionic structures, molecular structures covalent lattice structures and metallic structures

3D visualizations of different types of solids are constructed, where examples of ionic structures (sodium chloride), molecular structures (ice/water "fig 3"), covalent lattice structures (diamond, graphite structures), and metallic structures (copper) are presented.

In ionic structures in the case of sodium chloride, it is shown that sodium chloride has an all-round centered cubic grid "fig.4". Because Cl^- are much larger than Na^+, Cl^- are almost in contact to form a near-cubic structure of chlorine ion accumulation ions. Na^+ are placed in the pits forming Cl^-.

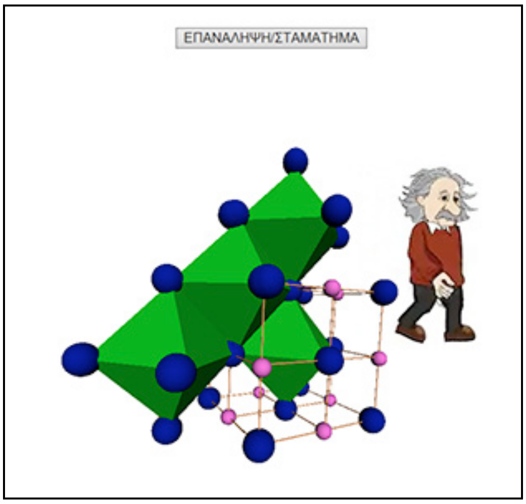

Figure 4. Crystal of sodium chloride described by Einstein, revealing the tendency of chloride ions (blue spheres) to link to several cations at specific positions.

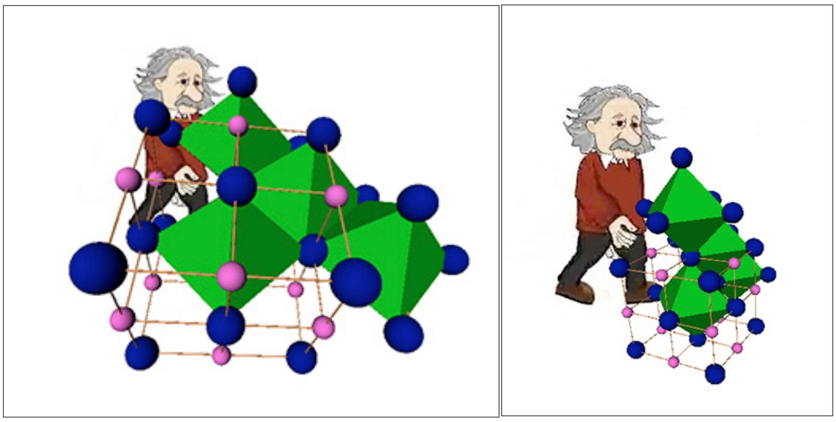

Figure 5. Crystal of sodium chloride employed by Einstein, where the user can rotate, minimize, enlarge or rotate the structure at any angle he/she prefers to observed and understand how Na^+ and Cl^- are linked.

In covalent lattice structures like the case of graphite (Fig. 6), carbon atoms have been sp^2 hybridized and joined together by (sp^2 + sp^2) bonds to form planes with hexagonal rings. Still, the graphite sheets are parallel and bonded together with weak Van der Waals forces, so the graphite has solid lubricant properties.

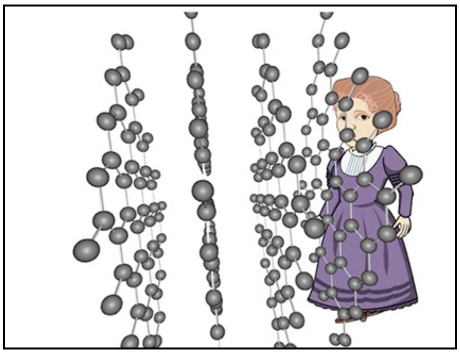

Figure 6: Structure of the graphite, showing its parallel leaves.

The diamond is a solid with a three-dimensional grid (Fig.7). Each carbon atom is covalently bonded to four others, and its three-dimensional grid explains its high hardness. The hybridization of each carbon atom is sp^3. Each C-C bond is formed by coating a sp^3 hybrid orbital of a carbon atom with a sp^3 hybrid orbital of a neighboring carbon atom.

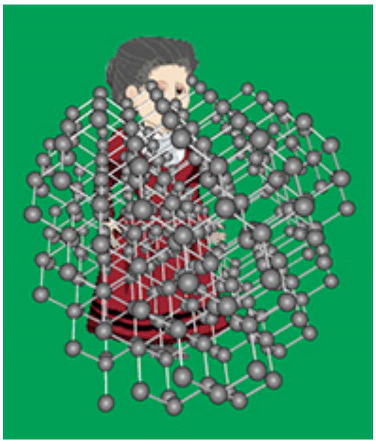

Figure 7: Structure of diamond, an example of solids with three dimensional grid.

As far as concerning metallic structures, the structure of copper is presented in “fig 8” in order to interpret its high electrical conductivity.

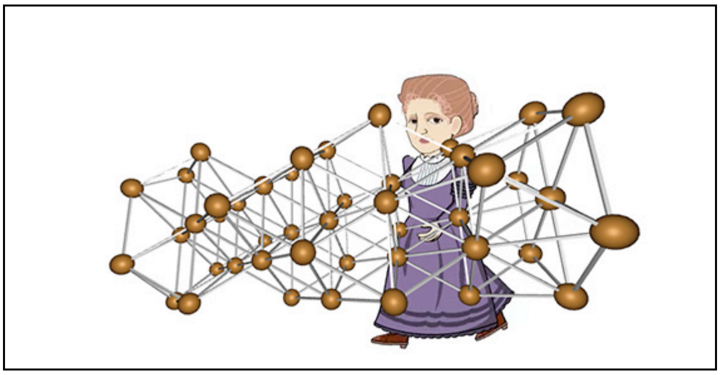

Figure 8. Copper in cubic grid (ccp), employed by Curie

2.2 Examples of atomic orbitals

In the case of atomic orbitals, which is shown in “fig 9”, the student has the capability to rotate the 3D visualizations of atomic orbitals for instance dxy, dz^2 at every axis he/she prefers and study them thoroughly.

Figure 9: Atomic orbitals dxy, dz^2

3 DISCUSSION - CONCLUSIONS

Special attention should be given to the creation of educational cartoons in order to facilitate the students' transitions between macrocosm, symbolic language and microcosm, which are the basic components in Chemistry science ([19]). It is obvious that chemistry concepts of atomic orbitals and crystal structures depend on visual spatial thinking, which consists of an ultimately essential set of skills that is too important to be left to development by chance ([20]). Towards that direction feather research in chemistry must be focused in visual and spatial thinking, as it is not a unidimensional mental skill- as it is often believed- but a complex grid of interrelated abilities involving perception, memory, logic, and creativity in the area of Sciences.

Many researchers such as Keller ([21]) have proposed to create designs which include pedagogical agents to enhance learning and motivation in computer-based learning contexts. In addition, agents were found to have positive effects on learners' motivation, academic success and cognitive load ([22]). Also it has been stated that pedagogical / cartoons agents should provide feedback by dialogues, facial expressions, hand movements and behaviours ([23], [24], [14]). So with the combinational usage of cartoons agents, this particular educational material was designed to up to a point to perform functions such as representing, emphasizing, pointing, describing, and expanding high level cognitive concepts that are able to cause misconceptions to undergraduate students in the high spatial ability scientific knowledge. So it is believed that it could be used as a didactical tool in-class or core-concept use and contributes to the understanding of the way that the simultaneous use of cartoons, humour and visualizations can help students in learning outcomes. A new method is proposed to be used by the teacher that could initiate the interest and consequently distract his/her students to communicate with them and to transfer and rebuild the knowledge that the teachers aimed to ([25]).

Moreover, in this paper it is proposed, that inserting cartoons (as an agent or as a supplementary tool) that employ 3D Visualizations into Higher Education could be a smart technique and strategy to heighten Undergraduate students self-efficacy and motivation which will, in turn, increase and restructure their scientific knowledge. Nevertheless, it is believed that the undergraduate students will convey fewer misconceptions about the conceptual nature of chemistry after viewing visualizations of atomic level concepts, strengthen their comprehension and the satisfaction of learning science, which is considered to be a high demanding task to achieve. So, a planned research will be carried out in the next period to explore and study the way students process the scientific knowledge and reconstruct at the Inorganic-General Chemistry courses, applied at three different schools of the National Technical University of Athens. Concluding, we aimed to emphasize the need for more systematic research exploring the impact of 3D visualizations employed by the funny and accessible cartoons agents on the learning process of high spatial ability chemistry concepts, in order to reduce the split attention effect of undergraduate students.

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