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Usability evaluation of 3-D visualisations augmented by cartoons for teaching solids and crystal structures in chemical engineering

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Abstract

In chemical engineering, undergraduate students often have to face the highly demanding process of understanding concepts from the microscopic level (e.g., ionic crystals such as zinc sulphide or covalent lattice crystals diamond, graphite, graphene etc.) and then explain with certain physical–chemical properties their macroscopic behaviour. Therefore, the main idea was to construct a specifically designed educational material that focusses on the benefits of viewing visualisations to enhance students' conceptual understanding of solids and crystal structures augmented by cartoons, and evaluate its usability. The interactive 'cartoons' agents were developed from scratch, giving them freedom of movement and realism at the same time. A research was conducted in the School of Chemical Engineering in Greece (National Technical University of Athens), evaluated the usability of the digital material and the contribution of the 3-D visualisations and the cartoons agents in the understanding of such high-cognitive load concepts.

Keywords: Cartoons, 3-D visualisations, crystal structures, chemical engineering.

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1. Introduction

In higher education, teaching basic science concepts has always been a major challenge, especially for thematic units addressed to chemistry and chemical engineering. This is mainly because students need to achieve a cognitive level that permits the understanding of concepts which are specifically related to the microscopic level, which is by definition a high-demanding cognitive process. Under that frame, students must be capable to visualise 3-D molecular shapes, understand and reconstruct principles that determine spatial arrangement, and also readjust their capacity to make the appropriate connections and realise how these principles affect spatial arrangements (Wang & Barrow, 2011).

For chemistry and chemical engineering, concepts that are related to microcosm can only be viewed by 3-D graphics because they appeal to a challenging and demanding spatial domain area. That basic principle is supported by the findings of Barrett, Stull, Hsu & Hegarty, (2015), who used a sample of college students without prior domain knowledge in organic chemistry and studied the effectiveness of virtual and concrete models for aligning and producing multiple representations in stereochemistry. The research findings confirmed the perception that 3-D 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. Moreover, an augmented reality-based 3-D user interface was evaluated by Maier and Klinker (2013), to enhance the 3-D understanding of molecular chemistry and their findings were positive too.

In a high-demanding learning process, which involves the understanding of chemistry concepts that combine the microscopic level with the symbolic language, cartoons have been shown to act as effective communication channels for science education. Cartoons are an art form, which it has been promoted to an important visual language, which basically affects human emotions and transmits messages using symbols and images. In recent years, they have been used in the field of sciences in primary, secondary and higher education (Dalacosta, Kamariotaki-Paparrigopoulou, Palyvos & Spyrellis, 2009; Keogh & Naylor, 1999; Roesky & Kennepohl 2008), since they have the potential to address a subject even scientific, without semantic ambiguities, often inherent in the written discourse. More specifically, studies exist that precisely analyse cartoon images of cloning and stem cell research (Giarelli, 2006), nanotechnology (Landau, Groscurth, Wright & Condit, 2009) and validate the efficacy of manga comics for chemical safety education to students in three universities in Japan, Taiwan and Thailand (Kumasaki et al., 2018). Also Kelly (2016) evaluated an electronic learning tool on precipitation reactions, which was designed featuring a cartoon chemistry tutor named 'Dr. NRG' who directs students through a learning cycle approach to explore the nature of precipitation reactions.

2. Digital material with 3-D visualisations and cartoons

The construction of digital material is based on the combination of educational interactive cartoons (agents) and three-dimensional visualisations, where the user has the ability to intervene through the controlled movement and also to select windows or android to watch it. Simultaneously, it aims at increasing the active participation of the student in the learning process, enabling him/her to control the pace and the way of learning.

The construction of the educational digital material was done in such a way that the applications run on all functional and most browsers with respect to the three dimensional, three js code and to achieve at the same time, the desired aesthetic level of the 3-D visualisations, in terms of their illumination and transparency. Also in the homepage was added js code, which recognises the user's device automatically (tablet, computer), runs in windows and android, and in the case of the resolution (greater or less than 800) automatically forwards the user to the corresponding version that has been created for the device and the operating system he/she uses.

Additionally, 'digital assistants-agents' cartoons, avatar type (Figures 1–3) have been incorporated into the educational material, which can facilitate the presentation and study of tricky abstract concepts, from the microcosm, by performing functions such as representing, emphasising, highlighting, showing, describing, adding and expanding. The construction of the material was completed by focussing on the concepts that the three-dimensional representations through the active participation of the student contribute substantially from the cognitive aspect to the understanding and study of the crystal solids, crystal structures, unit cells, metal solids, ionic solids such as zinc sulphide (Figure 1),

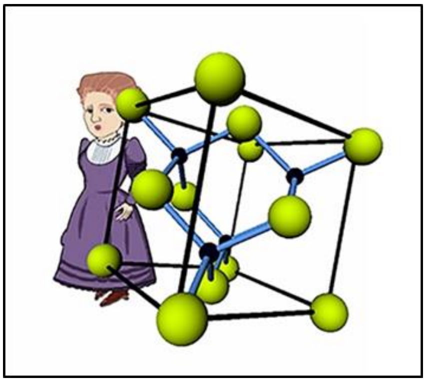

Figure 1. Unit cell of cubic ZnS, zinc sulphide

covalent lattice solids such as graphene (Figure 2). Graphene is a simple graphite layer, composed of hexagonally bonded sp^2 hybrid carbon atoms. These bonds are extremely strong, and yet they are flexible allowing the leaves to bend. So graphene is an excellent material, as there is a perfect order found on its leaves, with no individual defects empty spaces and these sheets are extremely clean, as only carbon atoms are present.

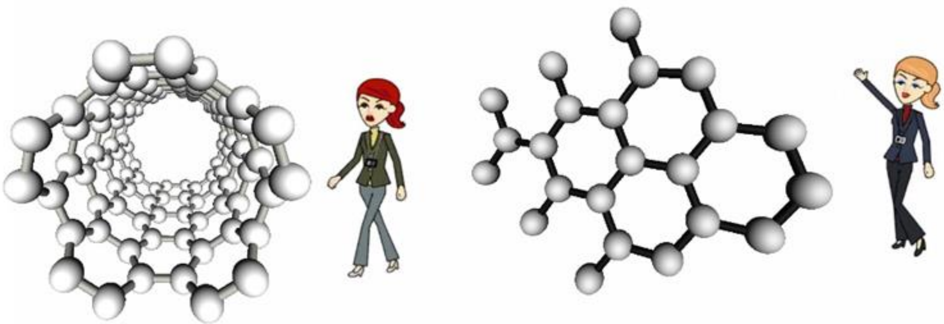

Figure 2. Carbon nanotube and grapheme

Also there is an additional reference to the superconductor ceramic, (yttrium barium and copper composition $YBa_2Cu_3O_7$) and carbon nanoparticles for e.g. the single-walled carbon nanotube, its structure includes single sheets of graphite (graphene) which are wrapped in tube shape and each nanotube is a single molecule made up of millions of atoms (Figure 2).

All three-dimensional representations have possibilities of rotation, magnification, reduction of structures, as exemplified in the examples of the hcp and fcc unit cells, augmented by Einstein and Darwin cartoons agents, which with the narration give valuable informations for e.g. that fcc unit cell, is a cubic unit cell which, apart from the grid points at its vertices, also has a grid point at the centre of each seat and the student can actually observe it (Figure 3).

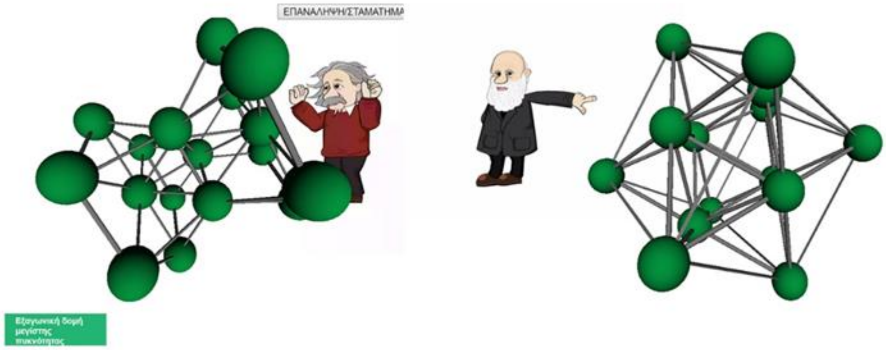

Figure 3: Fcc and hcp unit cells

3. Research

For the research a questionnaire with ten questions of Likert Scale, five point scales were used (Brown, 2010). A pre-test was made, using a sample of 10 researchers from National Technical University of Athens (NTUA) and undergraduate students from the first semester in the School of Chemical Engineering of the NTUA, in the Lesson General Inorganic–Chemistry. They were asked to see the digital material and then to fill the electronic questionnaire. This was only to 'check' the questions that evaluates the usability of the digital material with the 3-D visualisations of solids and crystal structures that were designed along with the cartoons agents. Moreover, we wanted to secure that the questions were the appropriate ones for the research that we conducted. So, the questions that were answered were checked for their validity and reliability, and the indicator Cronbach's Alpha as well as Total Item Correlation, between all the questions were calculated. In that case, the indicator Cronbach's Alpha was found equal to 0.716 and according to the values of the Total Item Correlation, one question was found to be marginally suitable and nine questions perfectly suitable. So it became apparent that one question needed corrections, which were made. Then, the control of the reliability and validity of the questions was repeated and it was found that all ten questions were found suitable, thus the indicator Cronbach's Alpha was found equal to 0.724 and the values of the Total Item Correlation were above 0.4.

In order to evaluate the usability of the combination of 3-D visualisations along with the use of the cartoons agents for teaching solids–metal structures–crystal structures and therefore their contribution to the learning process, a research was conducted in class. A sample of 50 undergraduate students from School of Chemical Engineering of NTUA was used, whereas the teacher let them use the digital material while she was teaching the specific concepts. They were given time to process the material as each student preferred in order to rotate, minimise or maximise the 3-D structures in the way that they wanted or listen to the narration of the cartoon agent. Afterwards, they were asked to fill the online questionnaire. The questionnaire included ten questions of five point scales (Extremely–Very–Moderately–Slightly–Not at all).

Additionally, a further consistency reliability analysis was conducted–based on Cronbach's Alpha test–using. The analysis was done for each question separately. Figure 4 represents the total correlation between the items and the Alpha coefficient, which shows the internal consistency if the specific item is deleted. As it is shown in all ten questions the total item correlation was above 0.5 and Cronbach's Alpha if item deleted above 0.750.

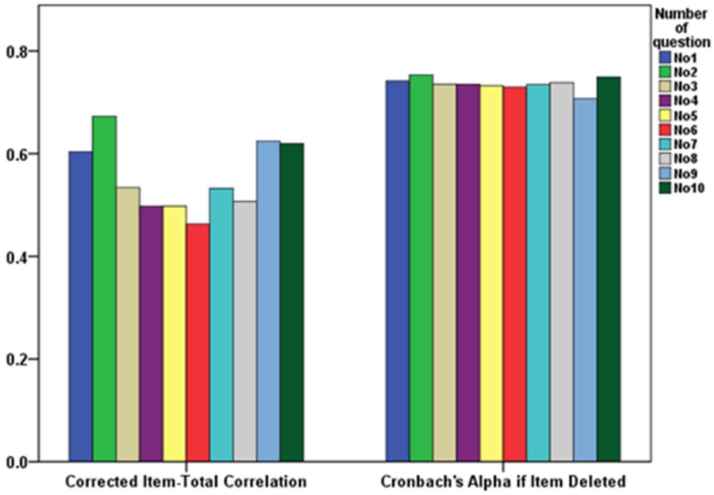

Figure 4. Values per question, the total correlation between the items and the Alpha coefficient, which shows the internal consistency if the specific item is deleted.

In the research, the students were asked to answer the questionnaire to express their opinion about the usability of the digital material regarding three factors. The first factor was whether the site was simple and functional in its use, so that could help the students in the deep understating of the presented chemistry concepts of solids and crystal structures. The second factor was whether the 3-D graphics helped them to better understand the teaching concepts, by giving them an active role (freedom to rotate or change the size of the structure by themselves) while they were using the material. The third factor was whether the combinational use of 3-D graphics with the cartoons agents had helped them to reconstruct their scientific knowledge. The results showed that the mean score was mainly above 4, which corresponds to the answer 'Very' (Table 1).

Table 1. Descriptive statistics

Number of questions	Minimum	Maximum	Mean	Std. deviation
1	3	5	4.22	.465
2	3	5	4.22	.428
3	2	5	4.02	.904
4	2	5	4.00	.695
5	3	5	4.08	.707
6	2	5	4.30	.837
7	2	5	4.56	.839
8	2	5	3.70	.818
9	2	5	3.94	.707
10	3	5	4.48	.716

That means that the majority of the students recognised the usability of the educational material regarding the understanding of such high-cognitive level concepts. Also the questions that rated the second factor gave that a total of 80% of the students had answered 'Extremely–Very', and furthermore a high percentage of the students 68% answered 'Extremely'. Moreover the questions that rated the third factor gave that a total of 72% of the students answered also 'Extremely–Very'. Finally, as it is apparently shown from the values of Table 1, none of the students gave the answer 'Not at all' and from the mean value it is obvious that an extremely low percentage of the students gave the answer 'Slightly' (<1% in the total of the ten questions).

4. Discussion– Conclusions

The present study gives an insight into how undergraduate students from School of Chemical Engineering (NTUA) can better understand scientific concepts with the help 3-D visualisations augmented by cartoons and how they approach them during their entanglement with the course of General–Inorganic Chemistry. The principal findings of this study showed that students' knowledge and understanding was helped, as students could actually visualise and examine the concepts of solids and their respective crystal structures. These concepts by definition require students to understand high-level mental processes, as they have the spatial ability and the cognitive skills to make the appropriate connections from microcosm to macrocosm. So apparently the educational material on purpose was designed with embedded 3-D visualisations and the auxiliary contribution of cartoons agents, to overcome obstacles that occur in the learning process. The research validated the usefulness of that educational digital material, as the students from their responses seemed to be enthusiastic since they were given the opportunity to use the capabilities of exploring, manipulating, rotating and viewing objects from multiple perspectives. More precisely, they could actually observe 3-D structures without the adequate plugins or programmes that run in all browsers and they could actually rotate them in each angle they wanted or changed their sizes and observed the kind of informations that they wanted and had difficulties to optimise them and understand them. On the other hand the role of the cartoons agents seemed to be substantial based on their acceptance they had from the undergraduate students as well as the symbolic use of humour they used (Hu, Lefton & Ludovice, 2016) and the positive effects had on learners' motivation, academic success and cognitive load (Dincer & Doganay, 2017). In general appropriately designed cartoons provide effective learning opportunities as they facilitate the diversification of scientific concepts, effectively restore prior student knowledge and overall promote the conceptual development process.

In addition, because the deep understanding and studying Chemistry concepts such as solids through their crystal structures (using three-dimensional imaging) depend on the user's visual-spatial thinking, which includes an ultimately necessary set of skills that are essential in the learning process, should not be left to 'luck' and without guidance to develop and evolve (Newcombe, 2013). To this end, in higher education further study and research should be conducted in Chemistry and Chemical Engineering and focus on visual and spatial thinking, as it is not a one-dimensional mental capacity–as is often believed–but a complex network of interrelated competences/skills that include perception, memory, logic and creativity. Especially, the role 3-D visualisations must be investigated, as many academics believe they can be effectively used to engage students in their learning, especially when visualisations are carefully designed to present information in an interesting manner and to explain abstract and complex concepts effectively. It is believed that it will create a more relaxing and entertaining learning environment in which students are more comfortable and motivated to engage in class by giving them freedom to interact.

Finally our research showed that the use of 3-D visualisations augmented by cartoons for teaching solids and crystal structures could be a smart technique and strategy, to strengthen undergraduate students' self-efficacy and motivation that will increase and restructure their scientific knowledge. To this end, the research will continue in the next period to evaluate the way students that process the scientific knowledge and how it can be improved, using the same concepts from the Inorganic-General Chemistry courses applied at School of Mechanical Engineering and also School of Applied Mathematical and Physical Sciences of the National Technical University of Athens.

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References

Barrett, T., Stull, T. A., Hsu, M. T. & Hegarty, M. (2015). Constrained interactivity for relating multiple representations in science: when virtual is better than real. *Computers & Education, 81*, 69–81. doi:10.1016/j.compedu.2014.09.009

Brown, S. (2010). *Likert scale examples for surveys, anr program evaluation, IOWA state university extension*. Retrieved from https://www.extension.iastate.edu/Documents/ANR/LikertScaleExamplesforSurveys.pdf

Dalacosta, K., Kamariotaki-Paparrigopoulou, M., Palyvos, J. A. & Spyrellis, N. (2009). Multimedia application with animated cartoons for teaching science in elementary education. *Computers & Education, 52* (4), 741–748. doi:10.1016/j.compedu.2008.11.018

Dincer, S. & Doganay, A. (2017). The effects of multiple-pedagogical agents on learners' academic success, motivation, and cognitive load. *Computers & Education, 111*, 74–100. doi:10.1016/j.compedu.2017.04.005

Giarelli, E. (2006). Images of cloning and stem cell research in editorial cartoons in the United States. *Qualitative Health Research, 16*(1). doi:10.1177/1049732305284019

Hu, D. L., Lefton. L. & Ludovice. J. P. (2016) Humour applied to stem education, *Systems Research and Behavioral Science, 34*(3), 216–226. doi:10.1002/sres.2406

Kelly, R. M. (2016). ConfChem conference on interactive visualizations for chemistry teaching and earning: insights into molecular visualization design. *Journal of Chemical Education, 93*(6), 1142–1144. doi:10.1021/acs.jchemed.5b00556

Keogh, B. & Naylor, S. (1999). Concept cartoons, teaching and learning in science: an evaluation. *International Journal of Science Education, 21*(4), 431–446. doi:10.1080/095006999290642

Kumasaki, M., Shoji, T., Wu, T.-C., Soontarapa, K., Arai, M., Mizutani, T., Okada, K., Shimizu, Y. & Sugano, Y. (2018). Presenting safety topics using a graphic novel, manga, to effectively teach chemical safety to students in Japan, Taiwan, and Thailand. *Journal of Chemical Education, 95*(4), 584–592. doi:10.1021/ acs.jchemed.7b00451

Landau, J., Groscurth, C., Wright, L. & Condit, C. (2009). Visualizing nanotechnology: the impact of visual images on lay american audience associations with nanotechnology. *Public Understanding of Science, 18*(3), 325–337. doi:10.1177/0963662507080551

Maier, P. & Klinker, G. (2013). Augmented chemical reactions: 3D interaction methods for chemistry. *International Journal of Online Engineering (iJOE), 9*, 80–82.

Newcombe, N. S. (2013). Seeing relationships: using spatial thinking to teach science, mathematics, and social studies. *American Educator, 37*(1), 26–31.

Roesky, H. W. & Kennepohl, D. (2008). Drawing attention with chemistry cartoons. *Journal of Chemical Education, 85*(10), 1355–1360. doi:10.1021/ed085p1355

Wang, C. & Barrow, L. H. (2011) Characteristics and levels of sophistication: an analysis of chemistry students' ability to think with mental models. *Research in Science Education, 41*, 561–586. doi:10.1007/s11165-010-9180-7