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Full Length Research Paper

Comparative evaluation of the effectiveness of 2 and 3D visualizations in students' understanding of structures of organic molecules

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Adopting quantitative approach using test as a key instrument, this study investigated the relative effectiveness of 2 and 3D visualizations on students' performance in the study of organic molecules, structures and nomenclature. The instrument was administered before and after treating two experimental groups with 2 and 3D supplemental learning software following a conventional teaching. The control group was made to interact with textbooks at the times the experimental groups were in the computer laboratory viewing the CD-ROMs. The study was conducted at a College in Lagos. The College had 205 chemistry students and of 205, 40% were randomly selected as the study sample. They were in turn randomly assigned to the three groups. Findings show that due to cultural and economical prejudice and long heritage of traditional teaching, assessment and learning system in place, many students are familiar with traditional system and they also feel comfortable with it. This is why the performance of the group making use of 2D visualization significantly better than the other group making use of 3D visualization. However, scores of students in both experimental groups were close which is higher than control group. Moreover, it is evident that the use of 2 and 3D visualizations enhanced performance in organic chemistry and thus one supplements other. Considering these, the simultaneous use of the two visualizations in the teaching and learning of organic molecules and structures based on closeness of the mean scores of the two experimental groups is suggested considering that 3D might prove more enhancing if students get used to it.

Key words: 2, 3D visualizations, effectiveness, organic molecules, structures and nomenclature.

INTRODUCTION

Chemistry is a visual science that relies heavily on symbolic representations to convey ideas (Balabau, 1999; Grabowiski, 2005). Also, chemical molecules are inherently three-dimensional objects that are represented by practitioners on paper and chalkboards through a system of two-dimensional notations. The paper and chalkboard presentation of organic molecules is a traditional way for classrooms practice. This practice experiences constraints and limitations resulting difficulty for practitioners to visualize the actual 3D structure (Tasker and Dalton, 2006) from what was described as dimensionally-deficient 2D drawings (Tenneson). This affects on both students' learning outcomes and achievement of good grade. These days, students are dissuaded studying organic chemistry since graduates are prevented from an employment that requires good understanding of and good grades in organic chemistry. Textbooks and almost all of efforts of teachers for illustrations of molecules involve the use of 2D drawing or sketches on paper and chalkboards. Because of these adverse situations, many students have no background in 3D visualization and have great difficulty in converting between the two-dimensional drawing used in textbooks and their three-dimensional structures (Barak and Hussein-Farraj, 2009).

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RESEARCH PROBLEMS

Recent surveys show a widespread use of visualizations and other 3D environments as tools for chemistry teaching. Researchers have also indicated both positive and negative impacts on learners (Falvo, 2008; Hundhausen, Douglas and Stasko, 2002; Tasker, 2005). Positive in terms of enjoyment, fun, motivation, attraction and other affective dispositions (Kelly, 2005; Naps et al., 2003; Prensky, 2001) and negative in what some students perceived as ‘fake’ and not authentic and misinterpreted when taking literarily (Falvo, 2008; Kelly, 2005; Kelly and Jones, 2005; Srinivasan et al., 2006). However, a review literature indicates that not much has been reported in terms of quantitative data of enhancement of learning outcomes at other levels, especially at cognitive level as the case were in web-learning and other technologies. The overall development of the students presupposes good performances at all of the three levels of learning outcomes not in attitudinal level alone.

RESEARCH AIM AND QUESTION

This study was designed to determine the effectiveness of this state-of-the-art technology on students’ performance in organic chemistry, particularly in the area of writing structural and molecular formulae, drawings and nomenclature of hydrocarbons and their derivatives. The effectiveness of the use of 2 and 3D visualizations on students’ performance was investigated. The question simply stated is; would 2D visualization enhance better performance of students in the above listed areas than 3D visualizations? More focused questions are:

(1) Would there be any difference in the mean scores of students in the experimental and the control groups?
(2) Would there be any difference in the mean scores of students that use 2 and 3D visualizations as supplemental after conventional teaching?

LITERATURE REVIEW

Recent evidences assert that without gathering proper knowledge, a few students in the field of chemistry especially in the area of organic molecules are able to ensure good grade investing a best effort to cope with this traditional textbook and chalkboard presentation (Schmidt-Ehrenberg et al., 2002). The current assessment procedure used in schools involves students’ production of responses as flat structures on paper. This approach helps the students in achieving a fake better grade without having an in-depth knowledge. However, strong arguments are provided for both provisions. While adherents of 2D explore many limitations for 3D for its usage especially in developing world because of technological, technical and human competency and financial constraints, proponents of 3D argue for sustainable and long term cost effectiveness, there is almost no alternative of 3D. The writing that follows explores the strengths and weaknesses of both 2D and 3D.

Discourse favoring 2D

Due to pre-setup and habituation, students may have struggled to form mental models of 3D versions, as found out by Wu et al. (2000), thus enhancing their performance. Researches also revealed that as further pragmatic aid and learning tool supplementary, many teachers frequently use ball and stick to stimulate 3D visualization in teaching isomerism in organic chemistry (Turkey et al., 1999). Looking at it from that perspective of students being able to manage or get by, researchers have frequently cited arguments in support of the use 2D illustrations. One such view is that students are more familiar with 2D drawings and illustrations as presented in textual materials they frequently interact with and that these 2D illustrations are more suitable for quick comparison when teaching structures in organic chemistry (Schmidt-Ehrenberg et al., 2002). Some have argued that students may not have a full grasp of 3D nature on the commonly available flat computer screen thereby generating more misconceptions and ambiguity than reducing them (Sinex and Gage, 2004).

Beside these pedagogical issues, there is also the economic aspect, making the present state-of-art-technology use in science education rather too expensive for many schools, particularly in developing nations to bear (Bon, 2007). The problems of access, poor internet connectivity and digital divide are there, making 3D viewing on computer impossible in many nations’ schools. Yet, the ability of these technologies in bridging the gap between concrete world of nature and the abstract world of concepts and models cannot be overlooked. They had been described as more of enablers of learning than of inhibitors (Barak, 2007). They should be embraced.

Discourse favoring 3D

Arguments for use of 3D visualization in science education are even stronger than these. In sum it is reported to be very effective in modeling abstract concepts and make what is abstract a tangible manipulable concrete (Dalgarno et al., 2003; Strangman et al., 2003). It is also argued that 2D illustration removes many information from the real structure and makes impossible spatial matching of structures (Romli et al., 2003; Barnea and Dori, 2004). This, 3D visualizations have taken care of it. It is equally documented that

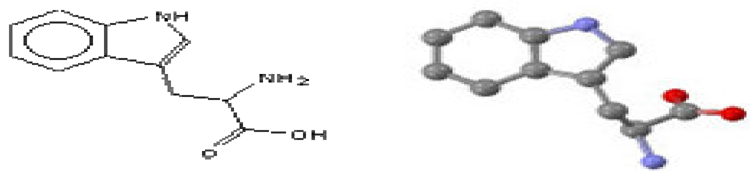

Figure 1. Diagram of 2 and 3D respectively.

Table 1. Comparative strength and weakness between 2D and 3D visualizations.

2D	3D
Strength	
Show complete structure	All available structural information present
Easy recognition of patterns	Understand shape
Chemists know how good structure look like	See what would be hidden with 2D view
Weakness	
Removes too much information from the real structure	Limited to viewing part of structure
Make impossible spatial matching of structure	Unsuited for quick comparison;
	Needs interaction to avoid ambiguities

Source: Adapted from Schmidt (2002).

understanding and achievement in chemistry and particularly molecular and stereochemistry are closely related to 3D visualization ability (Barak and Dori, 2005; Kelly and Jones, 2005; Tuckey et al., 1991; Tuckey and Selvaratnam, 1993; Tyversky, 2001).

Comparison between 2D and 3D

Schmidt-Ehrenberg et al. (2002) went further to draw a comparative strength and weakness between 2 and 3D visualizations. Users can make choice of which to employ more (Figure 1 and Table 1).

While many students have found encouragement using 3D visualizations and colourful molecular images to practice the use of different representations on computer (Barak and Dori, 2005; Barak and Hussein-Farraj, 2009; Ealy, 1999; Tasker, 2004) others were found to be more familiar with the use of dashes and wedges to represent 2D and semi 3D views, ball and spoke, ball and wire, skeletal and structural formulae which are widely used in chemistry courses (Ealy, 2004). According to Schmidt-Ehrenberg et al. (2002) students in the latter category who had mastered skeletal formulae found it a lot easier to write structures of hydrocarbons. They were found to perform well irrespective of whether the teacher used 3D ball and stick models in real laboratory or in computer laboratory through visualizations and animation. The students' performance might have also been enhanced because the teaching, the learning and response to paper and pencil tests used in schools follow the same pattern of drawing structures with 2D representation. This reinforces our hypothesis whether there is significant difference in students' performance on using 2 and 3D illustrations and visualizations in organic chemistry, particularly in drawing and naming of hydrocarbon molecules.

CONCEPTUAL FRAMEWORK

Research hypothesis

The above arguments point to two main important queries: the educational benefit from learners' perspectives and the overhead financial implications on the part of the school administrators making the whole exercise a kind of suspect. The question asked by Valdez (2005) "What prevents educational researchers from giving us definitive answers about technology in the classroom that would satisfy both critics and advocates?" is a pertinent one. Also crucial are the verdicts of no conclusive answer to the question whether technology promotes students learning or not (Ma and Nickerson, 2006) and ambivalent feeling and dichotomy among instructors and teachers reported by Barak (2007). In an attempt to provide answers to such questions and resolve the dilemma, the researchers were prompted to raise a working hypothesis for this study, that there is no significant difference between the uses of traditional 2D visualizations and the 3D virtual reality in learning when considered along pedagogical and economic gain. This study was specifically designed to test this hypothesis.

Genesis of visualization and role of 2D and 3D

Historically, the use of visualization began when scientists discovered the need to create a vehicle through which objects, events, phenomena or ideas can be conceptualized and understood (Gilbert, 1998, Gunes et al., 2004; Tregidgo and Ratcliffe, 2000). They are just like scientific models used in presenting ideas, concepts, rules etc like the case of Bohr model of the atom, the MIT bag model of the nucleon, the Gaussian-chain model of a polymer and the double helix model of DNA. Models are known to have played a central role and are used in a variety of ways in science education. So also it appears 3D visualizations have taken the central stage in science teaching and learning.

Visualization software emerged in the late 1980s (Brown, 1988; Stasko, 1990) for the purpose of creating and interactively exploring graphical representations of computer science concepts. It is the transformation of data or information into pictures and graphics in different dimensions that make human brains able to process such information. It is a tool to make sense of the food of information in today's world of computers (Schroeder et al., 1997; Songbo, 2004). Scientific researches rely strongly on visualizations for the study at micro level, nano-chemistry, or structures that are not physically accessible to human senses. Researches into these physically inaccessible structures benefit from computer reconstruction and rendering of data captured by imaging techniques or generated by simulations. Using visualization technologies, data can be represented in two, three, or even higher dimensions (Bhaniramka et al., 2000). Furthermore, users can change the value of parameters when visualizing data interactively such that more useful information can be gained from such visualization. The power of visualizations to illustrate and explore phenomena in chemistry teaching particularly the teaching of organic structures lie in the convenience of building molecules of any size and colour in a number of presentation styles (Barnea and Dori, 2004). As such they find valuable use in teaching the structures of simple as well complex organic molecules.

The 3D environments are characterized by the following features which make them inherently indispensable (Dalgarno et al., 2001).
The environment is modeled using 3D vector geometry, meaning that objects are represented using x, y and z coordinates describing their shape and position in 3D space. The user's view of the environment is rendered dynamically according to their current position in 3D space.

The user has the ability to move freely through the environment and their view is updated as they move (Dalgarno et al., 2001). User interactivity with the 3D display allows models to be rotated, zoomed and specific regions of interest to be highlighted (Barak and Nater, 2005).

While 2D structures on the other hand are linear in their topology and in the location of bonds connecting its atoms. They are also bone-explicit (Ramsay et al., 2002). The use of dashes and wedges, line-segment and condensed formula is prevalent (Ealy, 2004; Ramsay et al., 2002). The processing and searching of 2D chemical structures require that they are represented in a readable form. Efforts to make them equally effective in teaching and learning were supported by the use of animation for transformation (Kozuma and Russell, 2005; Thatcher, 2006). Animation in form of rocking can transform a static structure of 2D to increase the 3D scene perception. This technique could be used to create an illusion of 3D without any special device. Chalk-board, 2D drawing programs, pseudo 3D programs and physical models have been found to be effective teaching tools used to a large extent by most chemistry teachers and lecturers (Grabowski, 2005).

Research design

The design employed in the study is experimental of the pre-test, post-test and control group type. There were three groups, two experimental and one control. The design is appropriate as it controls for all threats to internal validity.

Population of study

The population of the study consisted of the entire senior secondary school class one (SSS I) students of King's College, Lagos, Nigeria. The number of science students in all the arms of the class was 205. The college is one of the leading and its choice was informed by the availability of computer laboratory and internet facilities that could aid science teaching and learning. The chemistry laboratory is also well equipped with apparatus, chemicals and models. Some of the students of the school are also computer literate. They could use online and offline soft wares in learning.

Sample and sampling technique

The sample of the study consisted of seventy five students that were randomly selected using systematic random sampling technique. The number was randomly assigned to the three groups namely two experimental and control groups. The two experimental groups were engaged in supplemental learning using Teaching and Learning Organic Structure and Nomenclature with Software (CDs) in addition to the conventional classroom teaching. The first experimental group used 3D viewers while the other used 2D skeletal formula and animation in computer laboratory one after the other after teaching. The control group interacted with the textbooks in addition to the teaching while others were in the computer laboratory. The choice of the SSS I class was to ensure that the subjects had not been exposed to those topics. The study was conducted ahead of time the students were to begin the study of carbon compounds one in the school curriculum/syllabus.

Instrument

Four instruments were used for data collection. The first was structured short answer questions on drawing, naming and identifying hydrocarbon molecules and isomers. They were prepared with accompanied marking scheme that awards one point mark throughout the questions. The second was structured four weeks lesson plans which were used in all the groups. The third was a CD-ROM of 3D organic molecular models of alkanes, alkenes and alkynes and their derivatives and isomers. The structures were constructed into ball-and-stick; wire-frame and space-filling models that can be viewed on desktop screen. The last one was a CD-ROM of flat surface 2D structures of the same molecules. The last two constituted 3D and 2D visualizations and were designed by Command College Enugu in collaboration with Project Development Authority (PRODA) also in Enugu. PRODA is one of the science and technology research centers established by Federal Government of Nigeria for the purpose of producing science curriculum materials and software for use in schools.

The lesson notes were highly structured as they contained all the relevant information on strategies, steps and evaluation questions that teachers need to teach the topics. The CD-ROMs were supplemental self learning packages used by the experimental groups in the computer laboratory. However, the number of periods and time of exposures in all the groups were the same. While the experimental groups proceeded to computer laboratory after teaching the control, spend the time with their textbooks learning the same topics.

A "panel of expert" technique was employed in establishing the content and construct validity of the instrument. This involved subjecting the instruments to analysis by experts, two academics in chemistry, the field that the instruments examined (Coll and Chapman, 2000; Coll et al., 2002) two in test and measurement and the remaining two were secondary school chemistry teachers. They agreed that the question items covered the objectives of the curriculum and were good. Test-retest determination of the test items with sample of 20 SSS I chemistry students outside the sample yielded 0.78 reliability coefficients.

Data collection and analysis

The three groups of students were taught by one of the regular college chemistry teachers for three periods of 1 h each a week for four weeks. After each period, the groups were in turn subjected to another 30 min interactivity session with 2 and 3D CD-ROMs for the experimental and textbooks for the control. The interactivity sessions were overseen by two of the researchers based in the study area whom also monitored the teaching and were satisfied with the procedure. The test items were administered before and after the four week sessions and marked by the same teacher using the prepared marking scheme to generate pre-test and post-test data. The mean scores of the groups in the pre-test and post-test are shown in Tables 2 and 3 respectively. The use of the students' regular chemistry teacher was to ensure uniformity and eliminate biases.

The mean scores of the three groups were compared to determine if there were significant differences among them using analysis of covariance, ANOVA and shown in Table 4. The direction of superiority of the treatments was determined by carrying out post-hoc analysis using Turkey's Honesty Significant Difference (HSD) test as shown in Table 5.

Table 2. Mean performance of students in pre-test.

Treatment	Mean score	No. of students
2D visualization	21.72	25
3D visualization	22.30	25
Control	21 - 56	25

Table 3. Mean performance of students in post-test.

Treatment	Mean score	No. of students
2D visualization	64.00	25
3D visualization	58.60	25
Control	42.40	25

RESULTS

Table 2 shows that there was no difference among the means of the three groups on pre-testing. Any observed differences there after could reasonably be attributed to the treatment.

Table 3 shows the post-test mean score of group one is the highest, meaning that the students exposed to 2D after teaching performed the best.

The superiority of the group that used 2D visualizations was confirmed by the information presented on Tables 3 and 4.

DISCUSSION

The results of this study show a significant difference in the performance of students within the groups, with the experimental groups performing better than the control. In the experimental, the group making use of 2D visualization performed significantly better than those making use of 3D visualization. However, scores of students in both experimental groups were close and higher than those in the control. This shows that the use of 2 and 3D visualizations enhanced performance in organic chemistry and are thus better supplemental. Similar discoveries were made by Morgil et al. (2004) and Sanger and Badger (2001). The experimental groups in their respective studies recorded enhanced achievements in complexation chemistry and molecular polarity and miscibility with computer visualizations over traditional methods. However, there were no distinctions made concerning effectiveness of 2 and 3D visualizations. That the 2D group performed better than the 3D group might be as a result of their familiarity with the plain resource devoid of much animation as found out by Ealy (2002). Beside this, many teachers complained of unavailability of 3D models and computer facilities in schools (Savec et al., 2006). If these equipment and software are not available in schools both teachers and students would not have any option than to rely solely on the use of 2D visualizations. Such heavy reliance might have accounted for the higher mean scores of 2D groups. Additionally, Falvo (2008), Tversky (2003) and Martin and Tversky (2003) noted the problems many students are likely to face while viewing animations. Such problems include misconception; misinterpretation and mis-representation which might hinder rather than enhance performance. Some students were carried away with the fun and attraction. These problems were noticed among the 3D students during the sessions. Even when the re-searchers made concerted effort to make students focus on the objectives of the exercise many of them took the exercise literarily the same way children take recreation with video and computer games, TV and action movies. This attitude was observed by Falvo (2008), Gredler (2004), Simpson (2005) and Squire, Glovanetto, Devane and Shree (2005). This might be one of the reasons why Leahy and Sweller (2004) cautioned that the use of animations and simulation must be in line with the principles of learning so as to make them facilitative and effective. Kelly (2005) and Suits (2000) on the other hand suggests due explanations and instructors' scaffold to address misrepresentations. In spite of the above explanations regarding students' familiarity with and in support of 2D visualizations and the corresponding strange attitudes and behaviour toward the use of 3D computer models, studies like that Savec et al. (2006) and the excitement shown by this study sample indicated that 3D might be more facilitative if students get use to them. It is based on this fact that the authors recommended the simultaneous use of the two visuali-zations during the transition period when the facilities will be available in all schools particularly those from the dev-eloping countries example of where the study was located.

Table 4. Summary of ANOVA: Post-test comparison of means.

Source of variation	Sum of squares	Mean value square	Degree of freedom	F-value	Critical F- at 0.05
Between (treatment)	1728.4	8746	2	17.22	3..5
Within (error)	764	52.8	72		

Table 5. Multiple comparison of means of strategies: Turkey's honestly significant difference (HSD) test.

	2D visualization (x^1 = 64.0)	3D visualization (x^2 = 58.60)	Control (x^3 = 42.40)
2D visualization (x^1 = 64.0)	-	4.60*	20.20*
3D visualization (x^2 = 58.60)	-	-	24.80*
Control (x^3 = 42.40)	-	-	-

Conclusion

That the scores of the two experimental groups were closed, this suggests the need to employ both 2 and 3D visualizations in science teaching as this would enable the students to have compensation of whatever that is missing in the other. We conclude, based on the quantitative data and treatment used in this study, that the conventional practice involving the use of 2D flat surface illustrations is more facilitative. However, if students can gradually be familiar with the skills involved in spatial visualization the 3D environments, more enhancements will be achieved in the long run. Our work went in some ways to contribute to, if not resolving, the debate on effectiveness of 2 and 3D visualizations and may provoke further thoughts in the minds of the advocates as well as the critics of virtual reality in the teaching and learning of chemistry, particularly the structures of organic molecules.

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