MolyPoly: Immersive Gesture Controlled Chemistry Teaching System

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ABSTRACT

Currently, first-year chemistry students at the University of Tasmania learn about three-dimensional molecular structures using a combination of lectures, tutorials, and practical hands-on experience with molecular chemistry kits. We have developed a basic 3D molecule construction simulation, called MolyPoly, to help students grasp the concepts of chemistry easily through immersion and natural interaction with 3D molecules. It was designed to augment the teaching of organic chemistry with enhanced natural interaction and 3D visualization techniques. This paper presents the results of a pilot study conducted with the aforementioned chemistry class. Participating students were split into two groups; MolyPoly and traditional. The results demonstrated that the two groups have achieved similar learning outcomes at the end of the four (4) class sessions.

Author Keywords

Computer-aided chemistry teaching, Immersive environment, Natural interaction, Virtual Reality.

ACM Classification Keywords

H5.1. [Information Interfaces and Presentation]: Multimedia Information – Artificial, Augmented, and Virtual Realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces – Interaction Styles; J.2 [Computer Applications]: Physical Sciences and Engineering – Chemistry.

INTRODUCTION

Visual representations and physical models are commonplace in science teaching (Harrison & Treagust, 1998, Wu & Shah, 2004). One of their applications is to enhance the spatial awareness of concepts (Ferk et al, 2003, Barnea & Dori, 1996). In organic chemistry it is important for students to be able to understand the 3D relationship of the molecules to comprehend concepts such as isomerisation, intermolecular forces and reaction mechanisms (Copolo & Hounshell, 1995, Barak & Dori, 2001). It has been found that when students understand the 3D spatial arrangement of atoms and molecules, how this relates to the 3D and 2D representations printed in textbooks and how to transpose them into a diagram in order to communicate the particular molecule to another chemist, students do better overall in exam/test results, even when the question does not relate to the shape of the chemical (Wu & Shah, 2004).

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To help students comprehend the spatial environment of the molecule many different models can be used. Originally these were provided in the textbook which developed from 2D diagrams to pictures of 3D molecules in different formats – ball and stick, ball and cylinders and space-filling.

Figure 1. Chemistry molecule model kit

Limitations of physical models include the amount of sets available, the number of atoms (balls) and bonds (sticks) as well as the types of molecules that can be made (Barnea & Dori, 1996). As computers and ease of software development became widespread, so did the availability of computer-generated models of organic molecules.

Developments in computer generated molecules range from merely drawing a 2D diagram through to having a rotating 3D model of a molecule. Some of these applications have overcome the limitations of the physical models – not only those listed previously but also the different bond lengths and atoms sizes which occur within different bonding systems (Barnea & Dori, 1996, Barak & Dori, 2001). One of the main difficulties remains to students in being able to mentally picture a 3D molecule from a flat representation.

Due to the availability and cost of computer-simulated molecules, these are still not widely used (Barak & Dori, 2001, Barnea & Dori, 2000). Therefore the teaching tools that are commonly used in a University chemistry unit consist of textbook images, 2D diagrams and plastic models for spatial awareness of the molecule's shape.

This paper describes the evaluation of a chemistry teaching system named "MolyPoly", created specifically to research the enhancement of students' learning.

RELATED WORK

Much work is being done with immersive educational systems, notably in the field of medicine. CathSim allow students to practice with a virtual reality catheter simulator program. Results of a two-group test study found participants preferred the traditional method of practising on a mannequin's arm, showing more improvement than the group using the CathSim system. Researchers concluded that a combination of both methods might further enhance student learning (Engum et al. 2003).

Another virtual reality medical simulation, MIST, was tested on training surgeons. It was found to increase their efficiency in operating room performance and decrease errors. The users of the system made fewer errors than the Non-VR users (Seymour et al. 2002).

A further example suggested the high level of user engagement within an educational 3D computer game environment was a factor in the positive learning results. Carpentry students preferred to learn using the game, with increased content understanding and retention leading to delivered skill sets being considered more relevant (O'Rourke 2013).

DESIGN AND DEVELOPMENT OF 'MOLYPOLY'

MolyPoly is a 3D molecular chemistry teaching simulation with a gestural interface. Based on the original system called MolyMod developed by 3rd-year HIT Lab AU students, MolyPoly was developed to evaluate the effectiveness of a system that enables viewing of a structure from different angles, compared with traditional chemistry teaching methods. The setup consists of a Kinect Camera (positioned directly in front of the user) and Vision Space (3 large screen stereoscopic projection system), as illustrated in Figure 2.

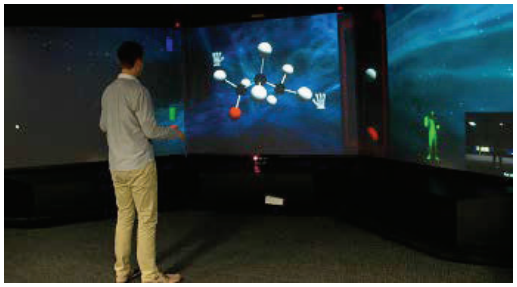

Figure 2. Interacting with the system in the VisionSpace.

The system was developed in C# using Unity 4 for rapid development. Two plugins were used with Unity; PlayMaker, a visual programming plugin, and a Kinect Wrapper**,** enabling access to the Kinect SDK.

The design of the MolyPoly was based on the following criteria:

- Immersive environment;
- Natural and engaging gestural interactions;
- Visualisation of 3D models with 3D stereoscopic view;
- Intuitive interface for the construction of molecules;
- Built-in lesson feedback accessible during lessons.

MolyPoly has 5 different levels (lessons) in which participants were required to create a certain molecular structure; Methane, Propane, 1-Propanol, 2-Propanol, and Methoxymethane. The built-in lesson feedback determined the correctness of the created molecule structure and provided basic clues as to why not completed (e.g. there are not enough carbon molecules).

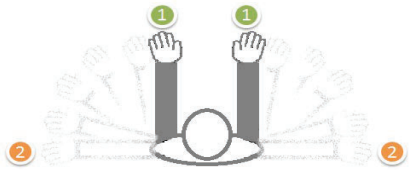

Figure 3. Performing the zoom in/out functions. Moving both your hands from point 2 to point 1 will zoom out, while moving your hands from point 1 to point 2 will zoom in.

Gestures were detected through the use of the Kinect skeletal tracking. The system can detect the movements of two hands,. The detection of the zoom gesture was determined by the same or opposite direction of the movement of the two hands (in the horizontal axis as illustrated in Figure 3) that was above a threshold velocity. The rotation gesture was determined by the movement of individual hand movements in horizontal and vertical axes. The left hand can rotate the structure down and spin it clockwise and in the opposite, the right hand can rotate up and spin it counter-clockwise. Both the zoom and rotation functions were triggered on and off with an onscreen button. For interaction, the user uses their right hand to pick up atoms from the right screen which can be joined to the main model. Their left hand can control functions.

EXPERIMENT

The experiment consisted of 4 sessions over 2 weeks. Seventeen students from the first-year chemistry class at University of Tasmania responded to the invitation to participate in the study. The participants were divided into two groups, MolyPoly and the Traditional method group based on their scores in a pre-test; therefore the two groups had similar ranges of students' subject knowledge. The traditional (method) group of students went to their normal chemistry classes and created molecular models using physical molecular model kits, whereas the MolyPoly group studied in the HIT Lab AU's VisionSpace, where they used the MolyPoly application to visualise and create molecular structures in conjunction with the printed hand-out of the lessons.

The pre-test was conducted to ascertain prior knowledge in order to get a baseline for comparison with post-test

after the lessons. The pre- and post-tests were identical and consisted of basic chemistry knowledge-related questions, mainly on molecular structure. In the subsequent two weeks, four (4) sessions with five (5) molecular structures were taught to both groups with different methods of teaching.

In the first session, participants selected for MolyPoly were shown how to interact with the application when they had an opportunity to get acquainted with the system and were tasked to create a simple molecule structure, Methane. During the second session (later in the same day but different lecture session), the participants were required to create propane, which is a more complex model.

In the second week, 1-Propanol was used in the third session, where the participants were instructed to complete the 1-Propanol structure and upon successful completion they were then able to view a completed 2-Propanol structure for comparison. In the (last) fourth session they were instructed to complete a Methoxymethane model. After all participants had completed the lesson, both groups undertook the post-test.

In addition, an extra (last) session was conducted in which both groups were swapped so that both groups had an opportunity to experience the other teaching method. It is worth noting that this last session has no influence on our comparative study presented in this paper since the post-test was already conducted in the previous session. Lastly, participants were asked to complete questionnaires on how both groups felt about the experience using the MolyPoly system.

RESULTS

The participants' results from their pre- and post-tests were collated and analysed. We calculated the improvement of each participant and compared the results using the t-test method. A two-tailed test was used for both the pre- and post-tests because we wanted to find if there was a difference in the improvement between the two tests for both groups of participants.

The traditional (method) group began with higher score than the MolyPoly group in the pre-test, as shown in Table 1. The standardised mean of pre-test scores was 28.89 and 35.33 (of total 100) in MolyPoly and traditional (method) groups respectively. We conducted a t-test and found that there was no significant difference between MolyPoly and traditional (method) groups in the pre-test because the T-statistic (-1.61) < T-critical (2.13) and the P-value (0.126) > 0.05.

Group	Number of participants	Pre-test(mean)
MolyPoly	9	28.89
Traditional	10	35.33

Table 1. Pre-test result

Both of the groups' post-test results steeply increased, as shown in Table 2. The average score in the MolyPoly group was 60.8, while that of the traditional (method) group participants was 72. However, the t-test revealed that there is no difference between the two groups results for the post-test, since the two-tailed T-statistic (-1.55) < T-critical.

Group	Number of participants	Post-test(mean)
MolyPoly	7	60.8
Traditional	10	72

Table 2. Post-test result

The average amount of improvement from the mean for the MolyPoly group was 36.19, while the traditional (method) group was 36.67. In order to test whether or not there were significant differences between two groups' improvement results from the pre-test to the post-test, the data was analysed by a t-test. A result of the T-test indicated that there was no difference between the improvement results, as the T-statistic (-0.09) < T-critical. Levene test for equality of variances, T-value is 0.930 and P-value is 0.367>0.05 so there is no significant difference in knowledge improvement between MolyPoly and traditional (method) group.

USER RESPONSE

The informal feedback received during the questionnaire produced some interesting results. The questionnaire contained 19 questions assessing the participants that have experienced the MolyPoly system during the sessions with Likert scale (Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4 and Strongly Agree = 5).

Survey responses showed that overall the MolyPoly group was more positive about the MolyPoly system than the traditional (method) group. Regarding *interaction*, participants were asked to consider whether the system was easy to use and interact with, the MolyPoly group was 3.4 (neutral) and the traditional (method) group was 2.4 (disagree). For questions pertaining to *experience*, the average score for the MolyPoly group was 3.7 (between neutral and agree) while the traditional (method) group was 2.7 (between disagree and neutral). With respect to *application usability*, the MolyPoly group was 3.3 (neutral) whereas the traditional (method) group was 2.7 (disagree).

Some participants stated that being able to view the 3D molecular structures from different angles contributed to a better understanding of the structure.

The MolyPoly group agreed that interaction with MolyPoly felt natural, the zoom gestures were easy to use and molecules displayed on a large display with 3D and "controller-free" interactions helped their understanding. This group mostly agreed that it was much easier to construct models in MolyPoly.

The traditional (method) group was of the opposite view of the MolyPoly group, disagreeing that gestures were

more natural and easier to accomplish. Unlike the MolyPoly group they believed that some chemistry knowledge is necessary to use the MolyPoly system for learning.

High interactivity was a feature of the system that participants from both groups found interesting. In particular, the rotation of the model to gain better understanding, "controller-free" interactions, natural zooming gestures, and the ability to get feedback from the system were identified as the best interactions with the system.

Despite this, many participants from both groups identified that the controls were difficult to use and functionality issues existed with the rotation of the model, bonding atoms together, and overall responsiveness to user input. In particular, participants identified that picking up and linking atoms was too slow and that gesture responsiveness needed improvement. This control inefficiency was also described by the participants as one of the main contributors to the time constraints. From these findings and observations during the experiment it was clear that further development work needed to be done to make the system a smoother and uninterrupted experience as well as an ultimately more effective tool.

Expression of a poor experience with the system and its little value for learning by the traditional (method) group on average may be due to their limited use of the system. The MolyPoly group had four separate sessions of exposure, giving them more time to familiarise themselves with the MolyPoly system.

CONCLUSIONS

This study assessed the effectiveness of using MolyPoly as part of chemistry teaching method and compared it to a traditional teaching method. This paper provides evidence that student learning with MolyPoly demonstrated similar improvement with the student learning with traditional lecture method. This can be explained by results from the qualitative questionnaire that indicated MolyPoly group students enjoyed their experience with the MolyPoly system and consequentially, kept students more engaged with the content.

While the results did not seem outstanding, one implication is profound. The fact that MolyPoly with no presence of a Chemistry expert achieved similar learning outcomes with the classroom teaching by a Chemistry lecturer implied that the visualisation techniques deployed by MolyPoly could potentially offer a viable solution for a remote delivery of the basic Chemistry lessons.

FURTHER WORK

Further work will address the usability issues identified with the system to make it easier and smoother for use in future tests. We will also attempt to use a larger amount of participants to find clearer patterns in the data. Furthermore, the relationship between user engagement and learning outcomes will be investigated further.

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