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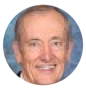

Patrick J. Garnett
Edith Cowan University

Ron Oliver
Edith Cowan University

Development of an Interactive Multimedia Package Designed to Improve Students' Understanding of Chemical Equations

Patrick Garnett[1], Mark Hackling[2] and Ron Oliver[1]
[1]*Faculty of Science, Technology and Engineering*
[2]*Faculty of Education*
Edith Cowan University, Perth, WA.

Abstract

Research indicates that students often fail to develop acceptable levels of understanding of chemical phenomena. Chemical equations and their interpretation is one aspect of chemistry where levels of understanding are limited and students often hold inappropriate alternative conceptions. One factor which contributes to student difficulties is the presentation of chemical equations at three levels: the macroscopic, the submicroscopic or particulate, and the symbolic. This paper describes the development of interactive multimedia materials designed to improve students' understanding of chemical equations. The materials include three modules dealing with molecular equations, ionic equations, and interpreting equations. The molecular and ionic equations modules include demonstration videos, particulate simulations, and instruction, with feedback, on writing balanced equations. The module on interpreting equations develops students' skills in interpreting equations by providing them with exercises which require them to work with equations at a particulate level.

Introduction

Alternative Conceptions Research

Research (Garnett, Garnett & Hackling, 1995; Nakhleh, 1992) indicates that it is very difficult for beginning chemistry students to develop adequate conceptions of the unobservable entities (atoms and molecules) and events involved in chemical reactions. The inability of students to visualise the submicroscopic particulate nature of matter and the processes involved in physical and chemical change represents a major barrier to students developing a scientifically valid understanding of many chemistry concepts. As a result, beginning students commonly exhibit a wide range of alternative conceptions concerning the molecular basis of chemical reactions and this subsequently affects their ability to write balanced equations, interpret the symbolic representations used in equations and solve problems based on equations. These alternative conceptions, as well as being an important concern in their own right, are also important in that they limit students' ability to interpret subsequent phases of instruction, particularly in a hierarchical subject like chemistry.

Several studies have investigated students' understanding of chemical equations and the processes they represent (eg. Garnett, Hackling & Vogiatzakis & Wallace, 1992; Ben-Zvi, Ceylon & Silberstein, 1987; Yarroch, 1985). Some of the alternative conceptions evident from these studies are listed in Table 1.

Table 1

Students' alternative conceptions: Balancing and interpreting chemical equations

1. Subscripts in formulas are numbers used in balancing equations (and do not represent atomic groupings).
2. Equation coefficients are numbers used to mechanically balance equations (and do not represent the relative numbers of species reacting or being produced in chemical reactions).
3. Chemical equations do not represent chemical reactions at a particulate level.
4. Chemical equations do not represent dynamic processes in which molecules/particles react with one another to produce new molecules/particles by rearrangement of the atom.

Yarroch (1985), in a study of Year 12 American students, found that about half the students who were able to balance chemical equations were unable to draw a reasonable diagrammatic representation of the equation at a particulate or molecular level. Students often drew representations which, while consistent with the total number of atomic particles involved, were inconsistent with the formulas of the substances involved and the coefficients in the equation. Yarroch concluded that many students had inadequate conceptions regarding the meaning of formula subscripts and equation coefficients. Students often regarded these as numbers distinguished by their location in an equation, and used to balance the numbers of atoms on both sides of the equation, but had little understanding of their chemical significance.

Ben-Zvi, Eylon and Silberstein (1987) found that substantial numbers of Israeli students also held inappropriate conceptions about both structural and interactive aspects of chemical reactions. Students commonly represented the molecular compound Cl_2O as two fragments, Cl_2 and O; and failed to distinguish between N_2O_2 and $N_2 + O_2$ when considering possible products of a reaction between N_2 and O_2. Student difficulties with the interactive nature of chemical reactions are illustrated by the reaction between N_2 and O_2; some students thought N_2O_5 could not be formed because of the need for three additional O atoms; others thought NO could not be formed because the mass of the products would be less than that of the reactants.

Garnett et al. (1992) investigated some Year 10 Australian students' abilities to balance chemical equations and apply an understanding of equations to 'simple' stoichiometry problems. As reported by Yarroch (1985) students were often unable to draw diagrammatic representations of equations and many students showed a lack of understanding of the different use of subscripts in formulas and coefficients in chemical equations.

In this study students also had considerable difficulty when asked to formulate an equation which described the reaction represented by 'before reaction' and 'after reaction' diagrams. Some students merely added up the number of species of each type in the 'before' and 'after' boxes with no recognition that one of the species was present in excess or of the need to simplify the coefficients in the equation. As well, many students disregarded the different meanings of formula subscripts and equation coefficients.

It seems apparent that many students lack a conceptual understanding of the submicroscopic particulate nature of matter and the changes represented by chemical equations. In addition, Andersson (1986) and Ben-Zvi et al (1987) identified students who held a 'static' rather than 'dynamic' understanding of chemical reactions. Such students failed to visualise chemical reactions as dynamic processes in which particles/molecules react to produce new particles/molecules by rearrangement of the atoms through breaking bonds and forming new bonds.

Clearly, many students' ability to balance and understand chemical equations is limited by their lack of understanding of the submicroscopic particulate nature of matter and their inability to visualise the dynamic nature of chemical reactions. This inability to visualise reactions probably also limits students' success in solving stoichiometric calculations, particularly where these are of a non-routine nature.

The difficulties students experience because of the abstract, unobservable, particulate basis of chemistry was previously described within the Piagetian epistemological framework (Herron, 1978) and several authors (Garnett, Tobin & Swingler, 1985; Gabel & Sherwood, 1980; Herron, 1978) advocated the use of concrete models to help students better understand the nature of matter. Modern multimedia technology has considerable potential to provide students with simulations of the submicroscopic/particulate nature of matter in its various states and the processes underlying physical and chemical change.

Chemistry at the macroscopic, submicroscopic and symbolic levels

Johnstone(1991) has proposed that chemistry is taught at three levels. The macroscopic level is sensory and deals with tangible and visible phenomena (eg. salt dissolving in water). The submicroscopic level provides explanations at a particulate level (eg. disruption of the ionic lattice and ions, surrounded by water molecules, moving into solution). The symbolic level represents processes in terms of formulas and equations (eg. $NaCl(s) + H_2O(l) \longrightarrow Na^+(aq) + Cl^-(aq)$). Johnstone believes that insufficient attention is given to understanding chemistry at the submicroscopic level and has pointed out the difficulty for students when teachers move quickly between these different levels. Perhaps it would be useful to students to point out these different ways of knowing chemistry, and to clearly identify for students which level of thinking is being used at any particular time. From the research evidence available at this stage, it appears that students have most difficulty in dealing with the submicroscopic which is, of course, outside their experience and can only be made accessible to students through the use of models, analogies or computer graphics.

Computer based instructional materials

Major difficulties for students of chemistry are the abstract, unobservable particulate basis of chemistry and the manner in which practising chemists and chemical educators move between the macroscopic, submicroscopic and symbolic representations of chemical substances and processes. These difficulties represent significant problems for chemistry educators but modern audiovisual technologies including the use of computer graphics provide exciting opportunities to present students with acceptable concrete representations of the particulate basis of chemical structure and behaviour.

Several studies (Hameed, Hackling & Garnett, 1993; Zietsman & Hewson, 1986) have indicated that it is possible to develop computer based instructional materials based on a conceptual change pedagogy which facilitate improved student understanding. This instruction is most likely to be successful when it provides visual concrete representations of unobservable processes and events, and causes students to reflect on their present conceptions.

Interactive multimedia describes an instructional technology with a number of critical attributes (Jonassen, 1988). In particular this medium includes opportunities for high levels of student engagement, the use of multiple media forms to represent information, and contextual feedback in response to student input. In addition IMM technologies are able to provide learning environments which are self-paced, able to cater for individual differences among students, learner centred, flexible in terms of time and place of delivery, and potentially offer a collaborative learning environment.

Interactive multimedia materials are eminently suited to the simulation of chemical processes using dynamic graphical representations of molecular interactions.
Tasker, Chia, Bucat and Sleet (1996) have reported recently on the VisChem Project which has developed molecular animations of a range of chemical processes aimed at improving students' understanding of the submicroscopic/molecular basis of these processes.

Description of the Project

This project developed an across-platform interactive multimedia package designed to help beginning students to understand the particulate basis of chemical reactions, their symbolic representation as chemical equations and to apply this understanding when balancing equations and solving simple problems based on equations.

The materials were designed to expose students to the three levels of chemical knowledge described previously, ie. the macroscopic, submicroscopic and symbolic levels, and provide an understanding of the particulate basis of chemical reactions. As well it was intended that the program provide opportunities for students to learn and practise the steps associated with balancing chemical equations. Finally the program aimed to develop students' skills in interpreting chemical equations at a quantitative level including an understanding of the concept of limiting reagent.

The project has developed three discrete modules that introduce students to chemical equations and develop skills in balancing equations and their interpretation. The materials are designed for use in lecture, tutorial or self-instructional modes. Two modules deal separately with 'molecular' and 'ionic' equations . A third module provides students with practice in the interpretation of equations.

Modules 1 and 2 both include instruction relating to eight chemical reactions. For each of these eight reactions students can:

1. View a video demonstration transformed into computer images. These images were intended to show students the actual appearance of a reaction when it occurs in real life. The purpose of this macroscopic view was to provide a link between the real world and the submicroscopic/particulate models chemists use to interpret chemical reactions;
2. View a simulation of the reaction at a particulate level; these animations use dynamic graphics that illustrate the behaviour of atoms and molecules and the transformations they undergo in chemical

reactions. The animations were designed to represent, at a particulate level, the processes that occur during chemical reactions using information that is available about these processes. In some examples where these processes are very complex, the process animations were simplified;

3. Write a balanced chemical equation. Equations are used to represent chemical reactions at a symbolic level. Students are provided with a particular approach to the balancing of equations which enables them to scaffold their knowledge. In this interactive program students are provided with a word equation and are asked to enter the formulas of each of the substances involved. Feedback is provided in relation to the chemical formulas written and also on the coefficients used to balance the equations. An option allows students to enter the physical states of all the substances involved.

Practice sets of twenty additional reactions are provided with both these modules to give students further practice in writing balanced chemical equations.

In Module 3 students develop their understanding of what chemical equations represent and their skills in interpreting equations. They are asked to interpret equations by drawing "before" and "after" diagrams to represent what occurs in a chemical reaction; do simple calculations to develop an understanding of the meaning of coefficients in chemical equations; and write equations to represent reactions illustrated by "before" and "after" diagrams. The concept of limiting reagent is introduced in some sections of this module.

Features of the IMM Materials

Use of Illustrations and Dynamic Graphics

The program was designed to make extensive use of video illustrations and animations using dynamic graphics. Levin (1981) has described the advantages of using these images in learning materials. From a cognitive perspective, graphics have been found to help learners focus their attention on explanative information and to aid them in organising information into useful mental models (Mayer, 1989).

Learner Interactivity and Engagement

The program was planned with a number of opportunities for learner interactivity and engagement. Planning of the interactions was guided by constructivist principles that place high levels of importance on learner activity in any instructional setting (Reeves, 1993). Constructivist epistemologies value learner-centred activities that facilitate personal involvement in creating and framing knowledge construction through students' cognitive activities (Lebow, 1993; Reeves, 1993). In multimedia environments, interactivity that leads to high levels of cognitive engagement appears to be an important aspect in achieving this.

Feedback

Feedback routines were carefully planned to encourage reflection among learners and to anticipate learning difficulties based on learner responses. A decision was taken to include oral feedback in certain parts of the program in place of conventional textual feedback. Cognitive load theory (Sweller, 1988) reasons that when viewing computer feedback in several forms, for example, animations and textual descriptions, the tasks create split attention with the learner attending to two discrete information sources. The theory argues that one of the sources can be neglected and the learning becomes inefficient and ineffective. The use of oral and visual feedback can reduce the split attention and lead to enhance learning outcomes.

Interface Design

In most CBL packages learner control is a key element of the instructional design and high levels of learner control are usually considered a positive attribute associated with increased learner motivation and achievement gains. The user interface for this program provided for higher rather than reduced levels of learner control. We planned to exert some instructional influence over naive users through implementation strategies that included a level of instructor support and scaffolding. The program content was organised in an hierarchical fashion which reflected a recommended instructional sequence but which placed little constraint on users' instructional choices. An aspect of the implementation of this project will be to investigate and explore implementation strategies that can be linked to high levels of learner achievement.

Conclusion

This IMM package was designed to improve students' understanding of the particulate/molecular basis of chemical reactions, and their ability to interpret chemical equations and solve problems based on equations. The provision of concrete representations of unobservable entities and processes, and the use of an interactive approach with associated feedback should facilitate students' achievement of scientifically acceptable conceptions of chemical equations and their application.

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