Designing interactive multimedia materials to support concept development in beginning chemistry classes

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Abstract: This paper describes a project which sought to develop an interactive multimedia package to help beginning students understand the particulate basis of chemical reactions. The project sought to develop a learning environment which would enable students to develop strong visual representations and mental models of the various elements through the use of activities built around dynamic and interactive graphical representations. The resulting program, Balancing and Interpreting Chemical Equations (BICE), provides opportunities for students to learn and practise the skills of balancing chemical equations and to develop skills in interpreting chemical equations at a quantitative level.

Key Words: interactive multimedia, chemistry learning, mental models, concept development

INTRODUCTION

Teachers of beginning chemistry students frequently report difficulties which many students experience in developing an understanding of chemical processes. Students appear to struggle to construct the forms of mental model and conceptual representations needed to understand and comprehend the actions of the unobservable entities such as atoms and molecules which are involved in chemical equations. Contemporary research suggests that this is a common problem among both secondary and tertiary students and represents a significant impediment to their learning and cognitive development (eg. Garnett, Garnett & Hackling, 1995; Nakleh, 1992).

Much of the explanation and description of the processes involved chemical reactions is given in terms of the actions of the various submicroscopic particles representing atoms and molecules. Students often have difficulty visualising this submicroscopic world and its components, a factor which creates a major barrier to their development of a scientifically valid understanding of many chemistry concepts. Beginning chemistry students often exhibit a wide range of alternative conceptions about the molecular basis of chemical reactions. They also exhibit limitations in their ability to write balanced equations, to interpret the symbolic representations used in equations, and to solve problems based on equations.

CONCEPT DEVELOPMENT

The difficulties faced by beginning chemistry students can be explained in part by factors associated with their development of appropriate mental models. Mental model theory is a field which offers theoretical explanations and descriptions of how learners develop an understanding of complex concepts and phenomena in science areas. The theory is a means of explaining human understanding of objects and phenomena since the construction of mental models is an essential part of the process of thinking (Genter & Stevens 1993). The process of thinking is concerned with the organisation and functioning of mental processes and representations and mental models mediate the interventions between perception and action (Wild, 1996).

Learners construct mental models in a number of ways. Many mental models are formed by experience and activity and serve to provide explanations concerning the way things work and interact. Such models tend to evolve and are prone to change as events and experience cause conflicts between predictions and reality. In science, for example, learners are frequently found to have constructed mental models of natural phenomena through naive ideas ahead of any formal science instruction (Driver, 1988). Often the mental models do not adequately explain the phenomena and need to be explicitly changed through appropriate instruction to more strongly represent the phenomena. Changing mental models involves reorganising existing knowledge structures and is a difficult process among learners with a variety of interpretations and understandings of the same event. The development of accurate mental models is an important aim of teaching and learning in the science domain.

The misconceptions and misunderstanding experienced by many beginning chemistry students are clearly associated with their inaccurate mental models. Andersson (1986) and Ben-Zvi et al. (1987) found that many students hold a static rather than dynamic view of chemical reactions. These studies revealed that students often failed to visualise chemical reactions as dynamic processes in which particles and molecules react to produce new particles and molecules. Early solutions which have been suggested to the problem involved the use of concrete models (eg. Garnett, Tobin & Swingler, 1985; Gabel & Sherwood, 1980) and dynamic graphical representations of molecular interactions (eg. Tasker, Chia, Bucat & Sleet, 1996). These solutions, while helping to develop an understanding at the particulate level, have not always been able to link this understanding to the other macroscopic and symbolic representation forms, a factor which can limit learners' development of appropriate and complete mental models.

More recently, interactive multimedia (IMM) has emerged as an instructional technology with the potential to overcome the limitations of traditional media in supporting the development of strong mental models of the particulate nature of matter. In particular IMM has the prospect to provide learning environments with strong visual elements which are dynamic, interactive and open, factors which have been shown in previous studies to support the development of accurate mental models (eg. Wild, 1996).

1. Interactive Multimedia and Visualisation

Interactive multimedia describes a technology with a number of critical elements which all have strong potential to support learning in complex domains (Jonassen, 1988). Perhaps the most promising aspect of a multimedia solution for the current problem was its capacity to support the use of interactive animations and visualisation. The use of visual images, animations and dynamic representations have been found in many instances to be effective devices supporting learning when used to demonstrate facts, concepts and rules (eg. Mayer, 1989; Rieber, 1991). The value of animations comes in part from the many ways in which visual representations aid information access, retention and recall and reduce the cognitive load associated with understanding text or other forms of representation (eg. Paivio, 1979). The use of interactive multimedia to provide dynamic and interactive images of chemical processes and reactions from a number of perspectives offers many opportunities for providing learner access to appropriate representations and for developing and supporting meaningful conceptions and relationships of the interactions of the constituent parts.

Rieber (1990a) suggests a framework to guide the appropriate use of animations and dynamic visual representations in learning materials and recommends their use only when the attributes of the animations are congruent with the learning task. In descriptions of the particulate nature of matter, the visualisation, motion and trajectory attributes of the various elements are critical elements in the description of the physical model and represent valuable and important components in an animated representation.

2. Knowledge Construction and IMM

Apart from the strong learning support which IMM can provide through its capacity to deliver meaningful and relevant content and information, the medium also supports the development of learning environments which facilitate and support knowledge construction and constructivism. Constructivism recognises the primacy of the learner and learning over instruction in educational settings (eg. Boyle, 1997). Constructivism describes learning as a construction process carried out by the individual learner through meaningful interactions within the knowledge domain (eg. Duffy & Jonassen, 1991). The role of knowledge construction is strongly tied to the development of appropriate mental models and many writers have described the potential of multimedia and computers to support this form of learning (eg. Wild, 1996).

THE MULTIMEDIA SOLUTION

The current project aimed to develop an interactive multimedia package to help beginning students 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 resulting program, Balancing and Interpreting Chemical Equations (BICE), provides opportunities for students to learn and practise the skills of balancing chemical equations and to develop skills in interpreting chemical equations at a quantitative level. It was designed to do this by providing opportunities for exploration of the three levels of chemical representation described previously, that is, the macroscopic, submicroscopic and symbolic levels, and through supporting activities and learning tasks which further contribute to the development of a conceptual understanding of the particulate basis of chemical reactions.

1. Content presentation

Cunningham, Duffy & Knuth (1993) proposed a series of design principles to guide the development of effective IMM-based learning environments. From a materials development perspective, they argue the need for realistic and contextual learning, the provision of multiple perspectives and multiple modes of representation. The BICE program was designed to support constructivist learning principles and was guided in its design by these elements. From a content delivery perpsective the program was designed to make extensive use of graphics, animations and illustrations in the delivery of its content. The program uses a broad cross section of sixteen different chemical reactions to demonstrate the variety of conceptual elements associated with the particulate nature of matter. Each of the reactions includes small differences to others with the set chosen to provide examples and cases of the many different concepts and principles needed for an accurate mental model. Each chemical reaction is represented in 3 forms at the submicroscopic, macroscopic and symbolic level.

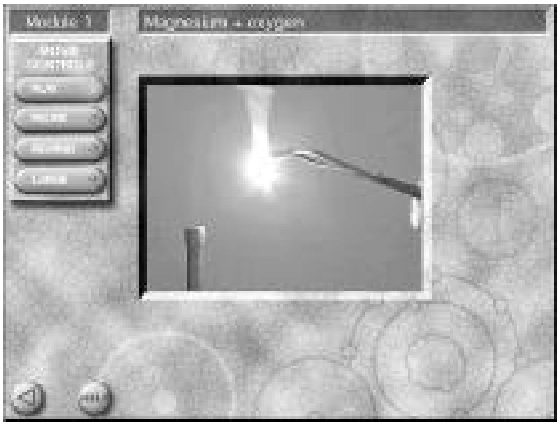

Figure 1.
An animation at the submicroscopic level representing the reaction between magnesium and oxygen. The animation provides many visual cues to aid the development of learners' mental models including molecular activity, relative particle sizes, orientations, molecular structure trajectories, and electron transfer.

Submicroscopic The submicroscopic representation is an animation of the particulate behaviour of the various elements in a chemical equation. The representation is provided in the form of a movie with a voice-over which describes in detail the actions of the various particles. The animation is accurate in terms of the relative sizes of the elements, their molecular structures, their motion and trajectory (See Figure 1).

Macroscopic The macroscopic level shows each of the chemical reactions in the form of an actual movie. Videotapes were made of the various chemical reactions and these are displayed with concurrent voice overs explaining the important aspects and activities of the reactants and the resulting molecules. Once again, the learners have control of the movie and can pause and continue as well as replaying the movie. A full screen version of the movie is available in instances when it is used as a demonstration (See Figure 2).

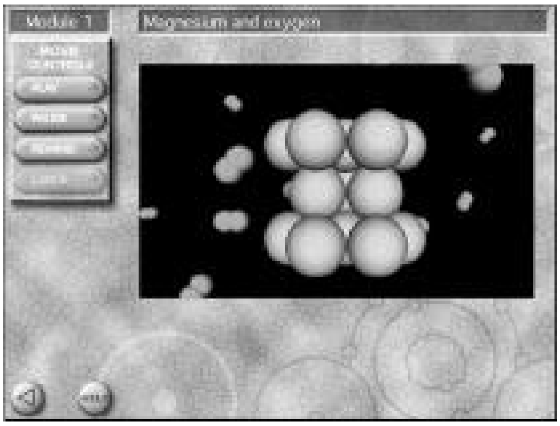

Figure 2.
The macroscopic level showing a video of the actual chemical reaction between magnesium and oxygen.

Symbolic At the symbolic level, learners are presented with opportunities to develop skills and understanding in writing chemical equations which represent the various chemical reactions. The activities are designed to draw from, and to reinforce, the mental models developed through use of the microscopic and macroscopic movies. The activities with the symbolic representations have been designed to provide many forms of learner support including contextual feedback, graphical images of the various components and intelligent feedback to guide learners at all stages.

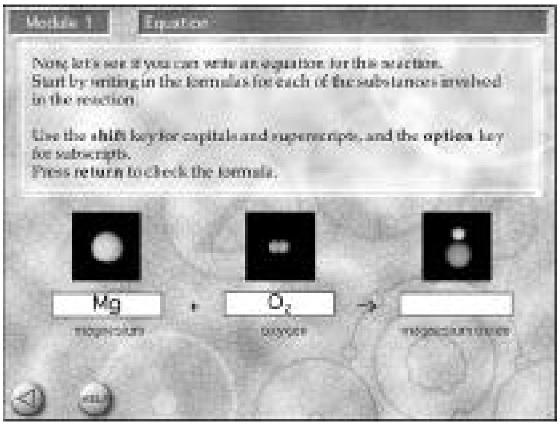

Figure 3.
A representation of the equation at the symbolic level. The learner is required to describe the reaction in the form of an equation. Feedback in the form of visual and aural cues are able to guide the learners if difficulties arise.

As well as providing the various representative forms of each of the sixteen molecular and ionic equations, the program also provides a range of practice activities. These provide an engaging environment to consolidate and strengthen students' mental models through further tasks involving balancing activities across many more discrete chemical equations (See Figure 3).

2. Interface and Organisation

The design for the interface for this program posed a number of problems. Since the program was being planned for naive users, it was appropriate to restrict the freedom of the learners and to impose some structure for their use to ensure that the content was covered in an appropriate sequence and that the attainment of prerequisite skills and knowledge preceded movement into more difficult and complex sections. On the other hand, the program was to include a vast array of media elements and their inclusion in a structured yet open mediabase had the prospect of greatly increasing the instructional and learning situations where this program could be used.

The interface provides for higher rather than reduced levels of learner control (Figure 4). We planned to exert 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.

Figure 4. The Menu Interface
The program uses a series of menus to provide access to the various components. Navigation buttons enable learners to return to previous menu levels to access other program components.

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 aural feedback in the feedback components in place of conventional textual feedback. Previous research has demonstrated the advantage of aural feedback in strong visual settings. When viewing feedback in several forms, for example, animations and textual descriptions, the tasks can create split-attention causing the learner to attend to two discrete information sources. One of the sources can be neglected and the learning becomes inefficient and ineffective. The concurrent use of aural and visual feedback has been shown to reduce the split attention and lead to enhanced learning outcomes (eg. Sweller, 1988)

3. Learner interactions

The program was planned with a number of opportunities for learner interactivity and engagement. The interaction design was guided by constructivist principles that place high levels of importance on learner activity in any instructional setting (eg. Reeves, 1993). Constructivist epistemologies value learner-centred activities that facilitate personal involvement in creating and framing knowledge construction through students' cognitive activities. (cf. Lebow, 1993; Reeves, 1993; Rieber, 1990b). The program was planned to provide a setting which provided many opportunities for learners to be actively engaged in meaningful learning tasks.

Apart from information presentation and elaboration, the graphics and animations in this program were designed to serve as part of practice and rehearsal activities associated with self-paced learning. The program was designed to foster student controlled interactions which support such cognitive activities as hypothesis formulation and informal hypothesis testing (eg. Rieber, 1990b; Rieber & Hannafin, 1988). Such activities enable students to develop mental models and to work within the environment to manage and resolve conflicts that arise in the formulation of their own models. Decisions concerning the ways in which the visuals, the sound overlays and the learner control are presented and used were all influenced by research and writing in this area (eg. Mayer, 1989; Paivio, 1979). The various components were selected to provide a learning setting which provided the greatest assistance to learners to visualise the abstract processes and which combined the various media in ways which complemented each other.

4. Implementation Strategies

One of the major problems associated with the use of instructional technologies is choosing appropriate implementation strategies. Frequently well designed materials fail to provide expected learning outcomes because they are not used by the students in a fashion which makes full use of the learning opportunities. At the same time, some instructors can elicit considerable learning advantage for their students from apparently low-quality learning materials, through the use of well crafted implementation strategies.

In our previous research we have been guided by the theory of situated learning (Brown, Collins & Duguid, 1989) and social-cognitive theory (Vygotsky, 1978). Both theories apply and extend information processing and constructivist learning ideas in ways which are well suited and potentially very powerful for guiding the design of IMM learning environments. Social-cognitive learning theory, however, contends that the principal factors influencing learning from multimedia are frequently independent of the learning materials themselves and derived from the manner in which the materials are implemented by the teacher and applied by the learners.

In developing the BICE program, due care was given to creating a set of instructional materials which could support these forms of learner behaviour in instances given appropriate teacher planning and organisation. The open-nature of the information and content organisation and the unstructured presentation format were designed in ways to provide flexibility and opportunity for teachers to be able to choose implementation strategies appropriate to their needs and those of their learners.

SUMMARY AND CONCLUSION

This paper has described the rationale behind the design and development of the BICE program, a multimedia-based program designed to enhance concept development in introductory chemistry programs concerning chemical reactions and equations. The IMM materials were designed with the aim of providing a means for teachers 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 learner activities was planned to facilitate students' achievement of scientifically acceptable conceptions of chemical equations and their application.

The BICE program make extensive use of the strong visual and processing capabilities of contemporary IMM to provide learners with access to a rich information source and appropriate activities to promote learning and understanding. The materials are currently being implemented in various introductory chemistry courses as part of an evaluation process. They are also being used in research studies which are exploring the effect of various implementation strategies on concept development and learner achievement. The application of IMM in this domain is well suppported by the extant literature and we are confident that our current research projects will confirm the relevance and the appropriateness of the strong theoretical basis which informed and guided the design process.

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