Learner-Centered Design of Chemation: A Handheld Tool for Middle-School Chemistry

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Abstract

Chemation, a simple 2-D modeling and animation tool for handhelds (e.g., Palm OS computers), was developed to help teach important chemistry concepts such as chemical reaction, conservation of mass, and the particulate nature of matter. Developing this tool required a learner-centered design approach. A deeper look at learner activities, goals and context helped to define the different types of support that needed to be included. This paper describes our design process including the analysis of the learning goals, context and learner needs which led to specific design requirements for Chemation. Finally, we describe our evaluation of Chemation. Analysis of student interviews revealed that while Chemation was successful in supporting students with respect to some learning goals (e.g., animation of atom rearrangement to support distinction between chemical and physical processes), it also failed to support others (e.g., no support for distinction between substances and mixtures). Classroom observations revealed some potential usability problems (e.g., the varying quality of student animations). Plans are under way to revise Chemation in accordance with the design recommendations from this initial study and reevaluate Chemation in the classroom.

Introduction

National standards call for students to develop both deep understandings of science concepts as well as the ability to understand and do scientific inquiry (AAAS, 1993; NRC, 1996). Specifically, the standards specify substances and their properties, chemical reaction, conservation of mass, and the particulate nature of matter as target content learning goals for middle school students.

Research has shown that students have a number of difficulties with these concepts. Students often confuse physical changes (e.g., mixing or boiling) with chemical changes (Ahtee & Varjola, 1998). They also do not understand that in chemical reactions, the atoms and molecules comprising substances recombine (i.e., break bonds and make new ones) to create new molecules and thus new substances (Krajcik, 1991).

Focusing on the particulate nature of matter has proven to help students develop better understandings of such difficult concepts (Driver, 1985; Gabel, 1993). Atomic and molecular level descriptions help to explain the difference between substances and mixtures. Substances are made of the same atom or molecule throughout whereas mixtures are not. The difference between physical changes and chemical changes can also be illustrated using such particulate descriptions. In a chemical change, the atoms rearrange (break bonds and form new ones) to make new molecules whereas in a physical change, no bonds are broken or formed. Conservation of mass can also be explained more easily at the molecular level.

The Center for Highly Interactive Computing in Education (hi-ce) has developed a standards-based, inquiry-oriented chemistry curriculum (McNeill et. al., 2003) in response to the need for science curricula that directly address the important learning goals set forth by the national standards as well as the corresponding student difficulties (Kesidou & Roseman, 2002). The unit "How can I make new stuff from old stuff?" contextualizes the targeted chemistry concepts and scientific inquiry skills in real-world student experiences. Students conduct investigations, engage with real-world phenomena, and make use of particulate models to help them develop an understanding of important chemistry concepts. The use of models in the curriculum is intended to help students connect abstract particulate concepts (e.g., atoms, molecules, rearrangement) to the phenomena. A number of activities in the curriculum require students build physical ball-and-stick models (using gumdrops and toothpicks) to illustrate various concepts.

Chemation, a simple 2-D modeling and animation tool for handhelds (e.g., Palm OS computers), was developed to help support student learning of the particulate nature of matter in this curriculum, and also to provide an alternative to the physical ball-and-stick models. Developing a tool like Chemation required a deeper look at learner activities and goals to define the different types of support that needed to be included. Typical software development has three distinct phases - design, implementation, and evaluation. Specifically, the development of Chemation was guided by a learner-centered design approach (Figure 1) which calls for very specific kinds of analyses in the different phases of the process (Quintana, Krajcik & Soloway, 2003).

This paper describes the design process for Chemation including the analysis of the learning goals, context and learner needs which led to specific design requirements. Finally, we describe how the results of our evaluation of Chemation yielded some new design requirements for a new version of the software tool.

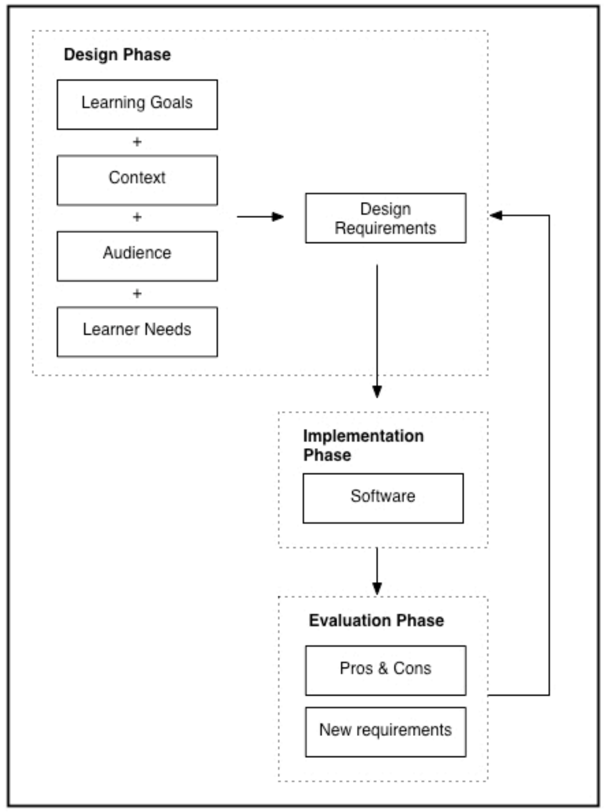

Figure 1. Learner-centered design phases

Design phase

The design phase of learner-centered design requires an understanding of the learning goals, the context, the audience/learner and the learner needs. This information is then used to define design requirements for the software.

In the case of Chemation, the learning goal was to understand substances, chemical reaction, and conservation of mass at the molecular level. The software needed to support middle-school students building molecular models to illustrate various concepts (e.g., substance and mixture) and processes (e.g., boiling, mixing, and chemical reaction). Understanding the types of difficulties students have with this content and those they have with physical ball-and-stick models helped to determine the kinds of supports the software would need to provide to address these learner needs. For example, the software needed to help students distinguish between physical and chemical processes by making the presence or absence of bond breaking and formation explicit. The software also needed make a clear connection between the icons and the atoms they were to represent so that students would not have to spend time decoding their models as they do with physical ball-and-stick models..

This careful analysis led to the following design requirements for Chemation. The software had to allow students to (a) easily identify different atom types, (b) place single atoms on the screen or connect them (with bonds) to form molecules, (c) delete atoms or bonds, (d) move individual atoms or entire molecules, (e) build an animation to illustrate a dynamic process, and (f) play back the animation. The following section describes the software resulting from these design requirements.

Implementation phase

Chemation allows middle school students to build 2-D models of atoms or molecules. Then, through a process of copying and modifying the model, students can create flipbook-style animations to illustrate various processes. For example, water molecules can be disassembled and rearranged to form hydrogen and oxygen gas, illustrating a relatively simple chemical reaction.

Chemation has three types of objects: atoms (or particles), links, and labels. Objects are created using the toolbar shown in Figure 2. When the atom tool is selected, a palette of atoms appears. Tapping the stylus on the screen creates an atom. Some atoms have element symbols on them and some do not. Those without element symbols can be used to represent other elements or even whole molecules. The colors and element symbols on the atoms serve to reduce students' cognitive load. Unlike the physical ball-and-stick models, students do not have to memorize which color represents which atom or even make this mapping. The link tool is used to connect two atoms. Links indicate the presence of a bond between two atoms, but are called links because they do not attempt to represent the type of bond (e.g., single or double). Atoms are linked by tapping sequentially on the atoms being connected. The text tool is used to create labels, which are free-form text boxes. The use of labels allows students to document the models they build, and thus make connections between the models and the corresponding phenomena they represent. Students can easily delete atoms, links or labels by simply drawing a line through them.

Flipbook-style animations are created through a simple process of copying and modifying frames. The toolbar in Figure 2 indicates that the water molecule is in frame 1. This frame can be copied by clicking on the "duplicate frame" button at the bottom right of the screen. The copy becomes frame 2 and can be slightly modified by adding, deleting, or moving atoms and adding or deleting links. Continuing this process of copying and modifying creates a series of frames that can then be played back for viewing by clicking the "Play" button next to the label tool.

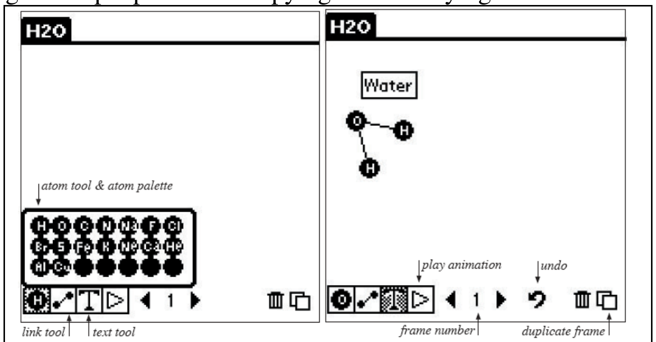

Figure 2: Toolbar and sample model

Evaluation phase

Our evaluation study (Chang, 2004) focuses on two teachers from urban schools and their seventh grade students. Each of these teachers had half of their classes use Chemation for the modeling activities in the curriculum and had the other half use physical ball-and-stick models (specifically gumdrops and toothpicks).

<u>Data collection</u>

Four lessons in the eight-week chemistry unit required students to use models. Classroom activities during the four lessons were observed and videotaped (one Chemation and one physical model class for each teacher). We interviewed three students after each class to examine their understanding of the lessons' chemistry concepts. A total of 29 students were interviewed and some students were interviewed for more than one lesson. We also interviewed the teachers after the unit to get their feedback on Chemation and the physical ball-and-stick models.

<u>Data analyses</u>

We analyzed student interviews to assess student learning after each lesson. Student responses were coded for conceptual accuracy at three levels: (a) proficient, i.e., all accurate components; (b) basic, i.e., some accurate components; or (c) unsatisfactory, i.e., no accurate components. Similarly, responses were also rated at three levels for thoroughness depending on the amount of detail in the student response.

During classroom observations, students were observed working with Chemation or the physical ball-and-stick models. These observations were intended to reveal general interface or usability issues.

Note that with such a small number of students and no strict control of variables we can not draw strong conclusions from this data. This study was intended to be informal and exploratory in nature. This first pass in the design process will help us to develop a more informed version of Chemation which can later be evaluated more rigorously.

<u>Student interview results</u>

Chang (2004) describes the following results from the student interviews. Some results confirm the utility of various Chemation features while others suggest new design requirements.

Students using Chemation were better able to describe chemical reactions and mixing. They more accurately identified the reactants and products and used more chemical names. We suspect that the element symbols and textual labels in Chemation may have supported students' use of scientific language to describe phenomena. These students were also better able to articulate that atom rearrangement was the difference between chemical reactions and mixing. The articulation of atom rearrangement through animation in Chemation seems to support student understanding of this idea quite well.

On the other hand, students using the physical models were better able to describe the main difference between a mixture and substance in terms of molecule constitution. There are currently no features in Chemation to support understanding of this distinction and it is not clear what the physical models did to support this.

Students using physical models also demonstrated better understanding of conservation of mass. We suspect that the physical permanence of the gumdrops makes it less likely to ignore them whereas in Chemation it is very easy to delete atoms from the screen. Students must be allowed to delete atoms while they are building their models. However when they are animating a process, deletion should not be permitted so that laws of mass conservation are obeyed.

Classroom observations

Observations of students in the classroom also suggest some new design requirements for Chemation. Both Chemation and physical model students continued to confuse atoms and molecules throughout the unit. Neither modeling tool provides support for this distinction. Chemation may actually contribute to this confusion. Some of the atoms in the palette are unlabeled so that they could be used to either represent other atoms or even whole molecules. Use of the same icon type to represent two very different entities is problematic.

The quality of animations in Chemation varied greatly among students. Some students created very smooth animations by making many frames with very small modifications from frame to frame. Other students used fewer frames and made larger changes from frame to frame. This resulted in jerky animations which do not convey the process as clearly as the smoother animations. Other students did not even use the “duplicate frame” feature. Their animations seem to flash as different atoms and molecules appear on each frame.

Although the nature of handhelds encourages ownership of individual work, the screen size is quite limited. This caused some problems for students using Chemation when they were dealing with relatively large molecules. Students could only fit a small number of molecules on the screen without overlapping them. When the molecules overlapped, it was difficult for students to see what was happening as they animated their model.

Next steps

Chemation was developed using a learner-centered design process so that it would target specific learning goals and take into account known student difficulties. Our analysis of student interviews revealed that while Chemation was successful in supporting students with respect to some learning goals (e.g., animation of atom rearrangement to support distinction between chemical and physical processes), it also failed to support others (e.g., no support for distinction between substances and mixtures). Our classroom observations revealed some usability problems (e.g., the varying quality of student animations). Future versions of Chemation need to attend to these conceptual and usability issues.

The next version of Chemation will address design requirements resulting from our initial evaluation. Specifically, Chemation must support: (a) The distinction between substances and mixtures in terms of their molecular composition; (b) Conservation of mass by somehow governing deletion of atoms during animation; (c) The distinction between atoms and molecules, perhaps by way of an explicit function to define groups of atoms as molecules. (d) Quality animations that clearly illustrate the details of the modeled process; (e) Efficient use of limited screen real estate. (This final requirement suggests that a desktop version of Chemation may be useful.)

Plans are currently being made to implement these design requirements. The resulting new version of Chemation will again be evaluated in terms of student understanding and usability but this time in a more rigorous and controlled study.

Acknowledgements

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References

Ahtee, M., & Varjola, I. (1998). Students' understanding of chemical reaction. *International Journal of Science Education, 20 (3),* 305-316.

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

Chang, H. -Y., Holt, L. S., Quintana, C. & Krajcik, J. (2004). Two alternative modeling tools to support middle school students learning chemistry concepts. Manuscript submitted for conference review.

Driver, R. (1985). Beyond appearances: The conservation of matter under physical and chemical transformations. In R. Driver (Ed.), *Children's ideas in science* (pp. 1450169). Philadelphia, PA: Open University Press.

Gabel, D. (1993). Use of the particle nature of matter in developing conceptual understanding. *Journal of Chemical Education, 70,* 193-197.

Kesidou, S. & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching, 39 (6).* 522-549.

Krajcik, J. (1991). Developing students' understanding of chemical concepts. In B. K. Britton (Ed.), *The Psychology of Learning Science* (pp. 117-147).

McNeill, K. L., Lizotte, D. J., Harris, C. J., Scott, L. A., Krajcik, J., & Marz, R. W. (2003). Using backward design to create standards-based middle-school inquiry-oriented chemistry curriculum and assessment materials. *National Association for Research in Science Teaching Conference Proceedings* (Philadelphia, PA). NARST.

National Research Council. (1996). *National Science Education Standards* Washington, DC: National Academy Press.

Quintana C., Krajcik J., & Soloway E. (2003). Issues and approaches for developing learner-centered technology. *Advances in Computers,* (57), 271-321.