Using Sonification and Serious Games to Support Learning of Complex Science Topics: The Case of Molecular Structures

Miguel A. Garcia-Ruiz
Department of Computer Science and Mathematics/Gaming Technology Lab
Algoma University

Isabel Molina,
Department of Biology
Algoma University

Biographical Notes

Miguel A. Garcia-Ruiz graduated in Computer Systems engineering and obtained his MSc in Computer Science from the University of Colima, Mexico. Miguel received his Ph.D. in Computer Science and Artificial Intelligence from the University of Sussex, UK. Dr. Garcia-Ruiz has been doing research mainly on human-computer interaction, where he has published three books, various book chapters and scientific papers on educational uses of sound in computer interfaces. Dr. Miguel was an Assistant professor with the College of Telematics, University of Colima, Mexico, and since January 2012 he is an Assistant Professor with the Department of Computer Science and Mathematics from Algoma University.

Isabel Molina received her B.Sc. in Biochemistry from the National University of La Plata (UNLP), Argentina. She initiated her graduate studies at UNLP and, since then, her research has been largely focused on plant biochemistry. After being awarded a Fulbright fellowship, Isabel continued her doctoral studies at Michigan State University (MSU), where she earned her Ph.D., and also worked as a post-doctoral researcher. Dr. Molina has published 12 peer-reviewed articles in international journals, including the educational journal Biochemistry and Molecular Biology Education. She has taught various undergraduate-level courses in the biological sciences and chemistry in Argentina, USA, and Canada. In July 2011, Dr. Molina joined Algoma University as Assistant Professor and Natural Products Biochemistry Research Chair, where she teaches Organic Chemistry and Biochemistry.

Abstract

Chemistry students often have difficulty in understanding abstract scientific concepts, such as structure and physicochemical properties of molecules. Visualization of either computer-based or physical molecular models has been effectively used in class, but it is not enough to support comprehension of some key molecular concepts, such as bond length and energy. Past research reports that sonification (the use of non-speech sounds to convey meaningful information in computers) has been employed to the study of molecular structure, facilitating comprehension of abstract molecular properties, which are

difficult to perceive through visualization alone. This paper describes a proposal for future research on the sonification of molecular properties of organic molecules, to be used in an educational setting. We will develop a serious game software (a game that has been designed for application beyond pure entertainment) as a test bed for our sonification ideas, due to the intrinsic audiovisual techniques, problem-solving and motivational features that serious games can offer.

Introduction

Undergraduate students generally have difficulty developing a conceptual understanding of chemical representations, including symbolic and molecular structures of Chemistry (Nakleh, 1992). Empirical studies (e.g. Ben-Zvi et al., 1987) have shown that many students do not easily understand the representations of molecules due to their scale (in the range of nm or pm), their abstract physico-chemical properties, and their intricate three-dimensional structure. Misconceptions often happen with the understanding of chemical bonding (Ozmen, 2004), a basic concept necessary to learn the nature of chemical reactions as well as the physicochemical properties of molecules, including boiling and melting points. Although students usually learn how to deal with molecular geometries using different formats (e.g., Fisher projections, Lewis structures, shorthand, etc.; Figure 1a), they still require to construct spatial reasoning and understand the three-dimensional arrangement of molecular structures (Harle, 2011). Traditional teaching tools (e.g. the blackboard or plastic molecular models) can be used to teach some general concepts about the structure of molecules, but they have certain limitations in terms of facilitating the understanding of very specific and precise properties related to the structure and dynamics of molecules. That is why students should rely on multisensory information, especially visual and tactile, and such information should be displayed to the student in a practical and accessible way (Durso, 2007).

The study and analysis of molecular structures and their properties have been conducted with fair success for some decades by visualizing graphical models of molecules in 3D (Figure 1 b-c). Most of these models have been shown in virtual environments (computer-generated three-dimensional spaces where a user can interact with the graphical representation) generally using desktop and laptop computers. Molecular model visualization has also been carried out in a very limited way using mobile computing, such as the so-called smart phones. According to Gilder et al. (2001), molecular visualization on mobile devices may be useful to explore basic molecular structures of proteins, and this type of visualization can be used in academic conferences, informal meetings, brainstorming sessions and other meetings where there is no immediate access to a desktop computer.

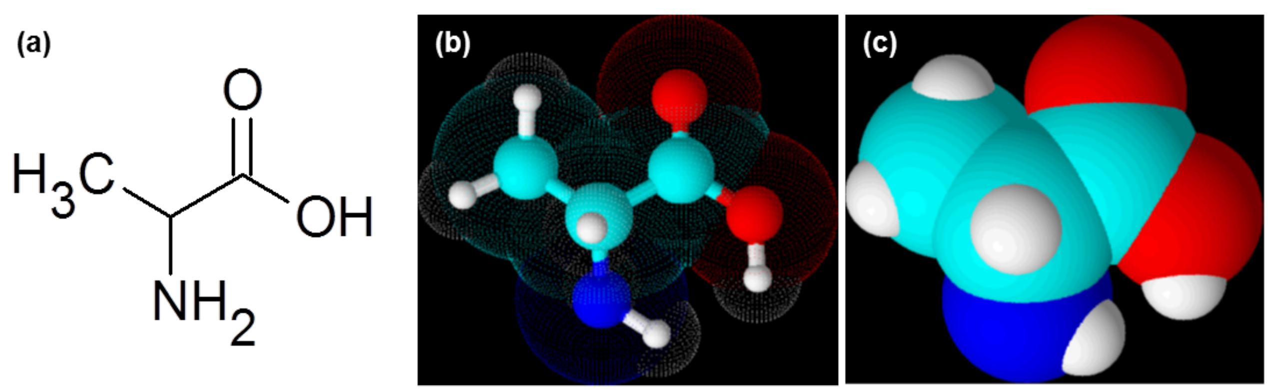

Figure 1. Molecular representations of the amino acid Alanine. (a) shorthand structure and **(b, c)** computer-generated 3D models: (b) balls and stick, and (c) spacefill representations, showing carbon atoms are in cyan, oxygen in red, nitrogen in blue, hydrogen in white. (These figures were generated using ACD/ChemSketch Freeware, version 12.00, Advanced Chemistry Development, Inc., Toronto, ON, Canada, www.acdlabs.com, 2012.)

Sonification of Molecular Properties

Recently, along with graphical visualizations, molecular information has been analyzed using other human sensory channels, mainly through computer-generated tactile (also termed haptic) molecular representations, and using auditory properties such as pitch to represent molecular information. These audio–tactile-visual combinations (multimodal interfaces) have been proven to help comprehend molecular behavior. What follows describes relevant research on auditory display applications for the study of molecules.

Past research reports that sonification (the use of non-speech sounds to convey meaningful information in computers) has been employed to study molecular structures, facilitating comprehension of abstract molecular properties, which are difficult to perceive through visualization alone. Non-speech sounds can be composed of digitally recorded or synthesized musical instruments (called earcons), everyday sound effects (called auditory icons), or electronically-produced pure tones (Blattner et al.,1989; Gaver, 1986; Kramer, 1994). For example, a group of piano notes (an earcon) could represent the number of bonds between two molecules, and could be played when a student makes a click with the mouse on the graphical bond. Similarly, a sound of a waterfall (an auditory icon) could represent hydrophilicity, indicating that the molecule that is attracted to, and tends to be dissolved by, water.

Miner and Della Villa (1997) conducted a three-day class activity where their secondary school students created musical compositions by mapping music notes onto DNA molecule base sequences assigning each base to a musical note from a particular instrument. After the 3-day class activities finished, the students offered a musical performance by playing their DNA compositions through musical instruments or a synthesizer. The students used a number of instruments like a saxophone and a harp to play the DNA songs. Miner and Della Villa observed mixed reactions from their students. Some of them found the sounds quite repetitive and boring. Others said the sounds sounded melodic, and some students liked them very much. The researchers also found that the sounds increased students' engagement and motivation to further learn more about ADN molecule. Garcia-Ruiz (2001, 2002) conducted a study on sonification of molecules using earcons (musical sounds) that represented data of amino acids (the molecular "building blocks" of proteins) in a virtual environment, otherwise difficult to analyze if their graphical models were solely visualized. Results of this research showed that amino acid sonification, in combination with visualization, is useful for conveying and recalling their molecular properties and structures. More recently, Cai et al. (2006) developed and tested a multimodal virtual environment edutainment system that showed interactive virtual molecules of amino acids. Cai et al. generated a sequence mapping from amino acids to musical notes of church organ, pan flute and synthetic sound to represent the secondary structural information of the amino acids. Their molecular sonifications have been successfully showed at the Shanghai International Arts and Science Exhibition.

Grond et al. (2010) recently developed an audio-visual computer program (a browser) intended for exploring and analyzing structures of ribonucleic acid (RNA) molecules, developing novel audiovisual representations of RNA shapes, adding extra sensory channels to support search tasks within the RNA molecule and facilitating comprehension of RNA shape information.

Learning Theories that Support Molecular Sonification

The research on molecular sonifications described in this paper agrees with a number of educational theories. Combining auditory and visual modalities should allow relief of learner's cognitive load (Mousavi et al., 1995), which in turn should facilitate learning of complex or abstract information, as described by Chandler and Sweller's Cognitive Load Theory (Chandler and Sweller, 1991).
In addition, the Cognitive Theory of Multimedia Learning (Mayer & Moreno, 1998) through its modality principle states that the information presented in a sensory modality can reinforce, complement or supplement the information presented in another sensory modality in an educational human-computer interface. That is, auditory information (sonification) may support comprehension of computer-based molecular model visualization.

Our Proposal

We propose to carry out future research on the sonification of molecular properties of organic molecules, to be used in an educational setting. We will develop a number of serious game prototypes (a serious game is a game that has been designed for application beyond pure entertainment) to be used as test beds for our sonification hypothesis, due to the intrinsic audiovisual techniques, problem-solving and motivational features that serious games can offer (Susi et al., 2007). We will focus on doing research on sonification of molecular bonding using serious games. This type of games offers learning with fun and engagement, and use current video game technology to support learning and training through simulation, as it happens with games for health, for military training, and science learning. Serious game technology (e.g. game engines and programming libraries) allow for sonification development and application of:

- 2D and 3D sound programming
- 2D and 3D graphics+ sound
- interactive sonification programming

In further sonification prototypes, we will let students choose their own sounds (auditory icons and earcons) from a repertoire. This could help them to remember the mappings. We will test new forms of mapping molecular structure information with non-speech and speech sounds, and will test different types of sound delivery media for playing the sonifications, such as headphones or hi-fi speakers, to see any differences in sonification perception.

Conclusions

Chemistry students have difficulty in understanding molecular structures taught by traditional instructional approaches. Visualization of either computer-based or physical molecular models has been effectively used in class, but it is not enough to support comprehension of some key molecular concepts. Past research reports that sonification (the use of non-speech sounds to convey meaningful information in computers) has been employed to the study of molecular structure, facilitating comprehension of abstract molecular properties. This paper described an introduction to sonification to convey molecular properties and empirical data on molecular sonification. The paper also described a proposal for future research on the sonification of molecular properties of organic molecules, to be used in an educational setting. We will develop a serious game to test our sonification ideas, due to the intrinsic audiovisual techniques, problem-solving and motivational features that serious games can offer. According to past research, student's learning relies on sensory information and thus sonification of molecular structure has great potential for educational applications. Advantages of sounds for educational applications include complementing/supplementing other human senses, and support of visually-impaired students. Our approach is to use sonification to support learning of molecular structures and and their abstract molecular properties. However, there are some drawbacks when applying sounds: some classrooms present acoustic challenges, and also, sonification requires careful design. These and other challenges will be addressed in our research.

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