Listening to Complexity: A Blind Person's learning of Chemistry with a Sonified Model

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Abstract

Students who are blind are usually integrated at public schools with sighted students. Since most of science education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and experimentation in science laboratories, students who are blind lack opportunities for participating and collecting first-hand information. The current research project is based on the assumption that the supply of appropriate information through compensatory sensory channels may contribute to science education performance. With the research system - Listening to Complexity system the user interacts with dynamic objects in a real-time agent-based computer model.

Keywords: Special Education; Systems thinking; Model based learning; Science education.

Introduction

Students who are blind have been integrated at public schools with sighted students for more than 60 years, and they are required to complete the same curriculum and examinations as sighted students. Since most science education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and experimentation in science laboratories, students who are blind cannot interact directly with such information resources. As a result of the lack of access to educational science material, students are left out or obtain only second-hand information (Bec-Winchatz & Riccobono, 2008). There is little research about how to apply science curricula and their impact on blind students' learning. There is a need to support science education and science teachers with appropriate tools and educational materials, which support students who are blind with equitable opportunities. Moreover, research into learning needs to accompany such development, to assess its affordances and limitations. The current research project is based on an assumption that the supply of appropriate information through compensatory sensory channels may contribute to science learning.

We provide students who are blind with equal access to the science classroom, by allowing students who are blind to interact with inquiry-based science materials. Other studies that have focused on science resources for blind and visually impaired individuals has also recommended using alternative sensory channels such as audio and haptic interfaces (Wies et al., 2000; Farrell et al., 2001). These studies have used audio feedback such as text-to-speech in order to read written material that appears on a website and a tactile map or haptic mouse to deliver a 2D spatial representation. In the current project, we focus on computer-based models that support inquiry learning through guided manipulation and obtaining information as to its results.

A few auditory assistive technologies were developed specifically for learning purposes, such as Talking Tactile Tablets (TTT) based on audio and 2D tactile materials (by TouchGraphics). This technology allows students who are blind to learn mathematics through interacting with 2D images such as geographic maps, representations of the solar system and math and science diagrams, (Landau et al., 2005) and the Line Graphs (Ramloll et al., 2000), which is based on auditory and haptic feedback. All the technologies described above allow the user to interact with a stationary object, and some of these technologies are based on a set-up scenario. Contrary to these, in the Listen to Complexity (L2C) system the user interacts with dynamic objects in a real-time agent-based computer model of a complex system.

Complex systems are made up of many elements, such as molecules in this study, which interact among themselves and with their environment. They are not regulated through central control, yet they self-organize in coherent global patterns (Bar-Yam, 1997). NetLogo (Wilensky, 1999) is a multi-agent programmable modeling environment supporting the creation of models of complex systems. Exploring such models in chemistry (visual representations) has been shown to be effective in helping students gain a deeper understanding (e.g. Kozma, 2000; Levy & Wilensky, 2009a,b).

Systems challenge our understanding, calling for reasoning at different description levels, considering interactions and relating between parallel events. When people reason about systems they frequently assume central control, assign behavior at one of the system's levels to another level (Wilensky & Resnick, 1999), focus on the system's parts and structure at the expense of attending to its function and mechanisms (Hmelo-Silver & Pfeffer, 2004), and a tend to view causal relations as a deterministic chain of consecutive causes and effects (Chi, 2005). Several innovative learning environments have been designed to help people overcome these biases and understand complex systems, e.g. constructing and exploring computer models (e.g. Levy & Wilensky, 2009a; Resnick, 1994; Wilensky, 2003) and role-playing participatory simulations (e.g. Colella, 2000). In this study, we have offered blind people an opportunity to explore computer models through the modality of sound.
This study grows out of the Connected Chemistry activities that use computer-based models for learning the gas laws and kinetic molecular theory in chemistry (Levy & Wilensky, 2009a). It views chemistry from an "emergent" perspective, how macroscopic phenomena result from the interaction of many submicroscopic particles.

Our research questions:
(1) What learning of the scientific conceptual knowledge is evidenced in the participants' answers to the pre- and post-test?
(2) What processes accompany the learning of the various concepts?
(3) Does the sonified representation of the gas model enable blind people to mentally model the dynamic gas system at both the micro- and macro-level?

The Environment

The learning environment is comprised of three elements: a computer model, a recorded voice guide to exploring the model and the interviewer. The computer model is a modified version of a model that was originally created for the GasLab curriculum (Wilensky, 2003) and then adapted for the Connected Chemistry curriculum (Levy & Wilensky, 2009a). The model includes gas particles in a container into which particles are added through a valve. The particular adaptation of the model for this study involves sonification of variables, locations and events. For example, the speed of a single particle is represented by an oboe whose pitch corresponds with its value.

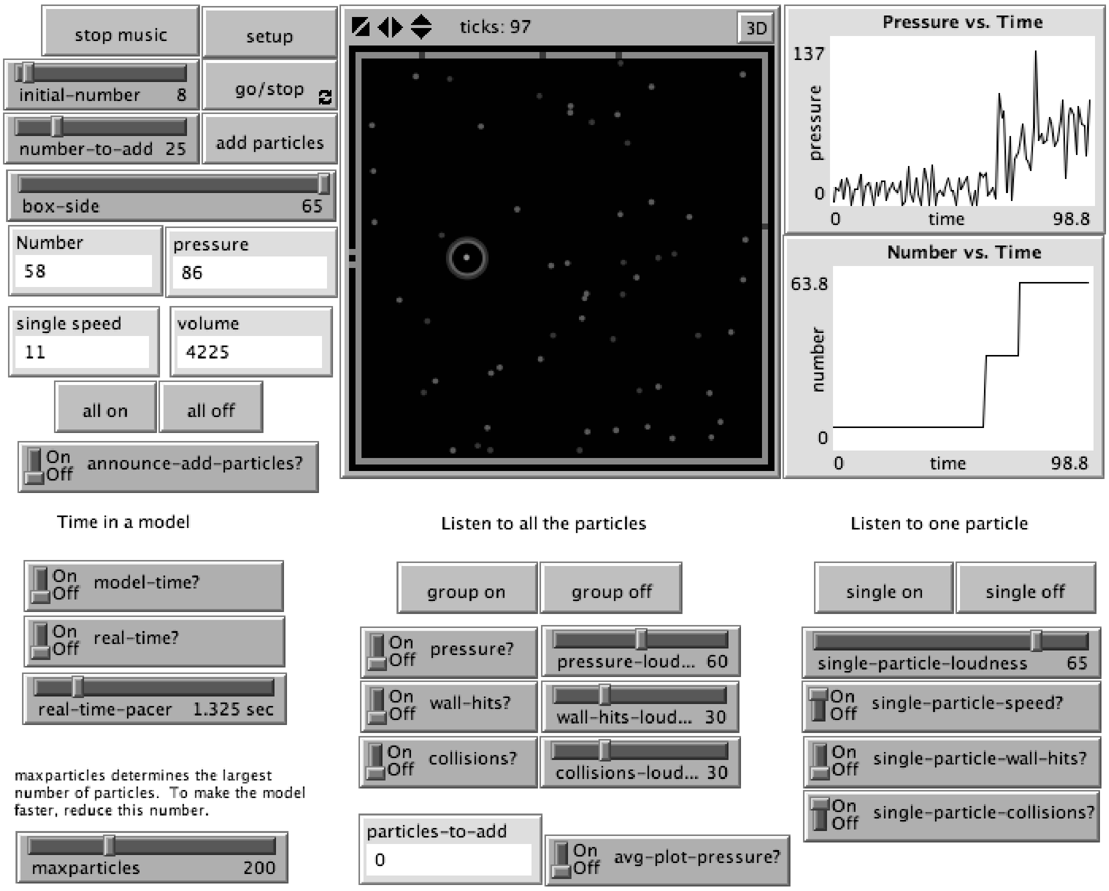

Figure 1. User Interface.

Method

Participant

The subject, R., is forty-four years old. He has been totally blind since the age of sixteen and has been using computers for 25 years. R. learned science in middle school and in college, including the topics in the study's environment: phases of matter and kinetic molecular theory of gases. R. has never used computer-based models or simulations.

Variables

Four dependent variables were defined:

Correctness of Model. The correctness of the model (100%) with respect to the scientific model, or as an alternative, a mental model (doesn't know, correct, and alternative)

Partiality of Correct Model. Number of correct components (out of 7)

Components of Model. This variable includes 17 components: matter is made of particles, straight line motion, change in direction results from hitting wall, change in direction results from hitting other particles, change in speed does not result from colliding with the wall, change in speed (either up or down) results from colliding with other particles, particles move about randomly, having more particles leads to greater frequency of collisions, greater density of particles leads to greater frequency of collisions, smaller volume leads to greater density of particles, smaller volume lead to greater frequency of collisions, smaller/greater volume doesn't change the average speed, smaller volume leads to a smaller distance between collisions, smaller volume leads to more frequent speed changes, having more particles leads to more speed changes, and having more/less particles result in the same average speed.

Levels in the System. To understand the participant's views of the system as complex, a number of features are noted. For this variable, the levels that are described and whether they are connected (doesn't know, macro, micro, both macro and micro) are coded. In addition to this variable, we look at interactions between system components, based on the codings for the variable 'components of model' for the interactive dimensions (items relating to collisions among objects).

Research instruments

The main instruments used in the study were:
NetLogo 4.1 (Wilensky, 1999). The application included a model of gas in a box based on auditory feedback.

Research Protocol. The research protocol included four tasks: feeling and pumping up a bike tire, listening to a particle (wall hits, speed, particle-particle collisions, collisions and speed, wall hits and speed), listening to air pumping in (a particle's collisions with other particles when air pumps in, a particle's speed when air pumps in), and changing volume. The four tasks included 20 open-ended questions before and after each task. No feedback was provided by the researcher.

In addition, a set of three instruments was developed for the collection of quantitative and qualitative data:
Background Questionnaire. This questionnaire included 17 questions about the participant's personal information (for example, name, age, gender, cause of blindness, age of onset blindness, visual ability), and science education background (middle school, high school, or later).

Pre- and Post-Test Questionnaire. Identical pre- and post-test questionnaires. The questionnaire included an overview of simulated air particles inside a bicycle tire and ten questions used in a previous study (Levy & Wilensky, 2009,b).

Recorded Observations. The participant was video-recorded during the task.

Procedure

The design of this study was a pre-test-intervention-post-test. The study was carried out in four stages. At the first stage, the study was introduced, consent was obtained, and background information was recorded. The second stage involved administration of the pre-test. The third stage included the intervention: (a) feeling and pumping up a real bike tire; (b) using the model to learn about a particle among other particles; and (c) using the model to learn about air pumping in. This intervention was followed by a post-test in the fourth stage. The study, which lasted 2.5 hours and was video-recorded.

Results

Research Question One: What learning of the scientific conceptual knowledge is evidenced in the participants' answers to the pre- and post-test?

R. shifted from 3/7 correct answers in the pre-test to 5/7 in the post-test. Improvement consisted of including gas particles in a bike tire representation, understanding particle-particle collisions and extending understanding of pressure to novel situations. Concepts that were not learned:

particles don't have intentions (animism), particles are distributed randomly throughout their container and that collisions between particles are distinct from collisions with the wall: the first results in speed change, but the latter does not.

Research Question Two: What processes accompany the learning of the various concepts?

R. started out with a fully macroscopic view of the system and an understanding that collisions among particles increase their speed while their collisions with the wall decreases their speed. Figure 3 describes the score regarding R.'s responses to the questions in the activity. These are graded as "don't know" (1), alternative understanding (2) and correct understanding (3).

Through the activities, his focus shifted to the submicroscopic particles and his misconstrued concepts came up against contradictions. In some cases, his reasoning shifted to a correct understanding; in others, he shifted into confusion, a preliminary phase to resolution. An example of a shift to a new understanding involves energy exchange when two particles collide: "I think that when they collide, the speed increases… I haven't a clue. I thought I had a pattern but it didn't work out… yea, I think it was up the speed and then it slows down as a result of the collision." A significant bridging of submicro- and macro-levels is seen in his understanding that pumping up more particles into the container does not change their average speed even though the speed itself changes more frequently. Understanding the random distribution of the particles location and speed did not improve from pre- to post-test. However, we can see his budding observation of such randomness when he tries to makes sense of durations between collisions: "Yea, I guess when it hit two particles back-to-back in a short period of time, it did not seem to repeat that… Besides that, it did not seem to be regular intervals. Umm, I mean between hitting different particles."

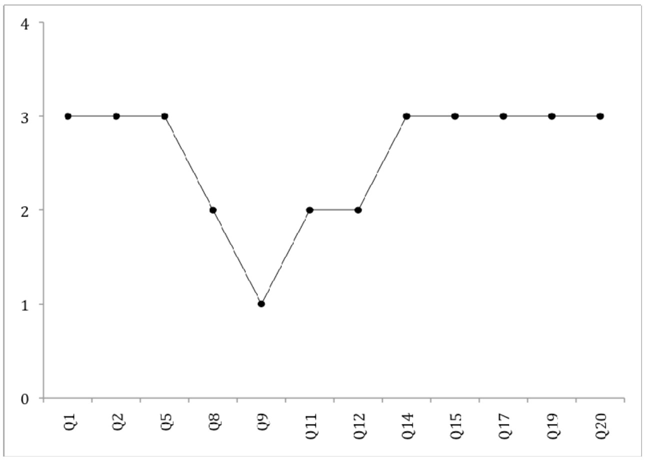

Figure 2. Progression of R.'s responses to the activity questions in terms of fit to the correct scientific knowledge

Research question 3: Does the sonified representation of the gas model enable blind people to mentally model the dynamic gas system at both the micro- and macro-level?

We note R.'s utterances that refer to making sense of the representations. For example, when listening to the particle hit the different walls of the container: "I can tell you that at some points it ricochets back and forth between the opposite sides." R. succeeded at integrating two sounds, after listening and connecting collisions and speed changes. In summarizing the activity, R. states: "Basically you're learning a new language."

R. suggests several improvements to the system: changing the pitch of the wall hits so that the walls can be better distinguished using no more that 5-6 tones so that the user can keep track of all the information, shifting control to the user regarding model manipulation, tone setting, and changing the speed of the model. In addition, he suggests adding an option to use recorded voice to state which wall is being hit.

We have seen significant shifts in R.'s understanding of the chemical complex system he explored through the sonified model. Some changes resulted in reconceptualization of the domain and others reflect his understanding that his previously construed concepts are not validated in the model.

From this study with R., we have learned of some of the central affordances and limitations of the L2C system. We are currently working on revising both the sonified model and its accompanying activity guide to better support learning, preserving successful elements and transforming those that were less successful, increasing user control and improving distinctiveness of the sound representations.

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