Listening to complexity: blind people's learning about gas particles through a sonified model

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ABSTRACT

Students who are blind have been integrated at public schools with sighted students. Because most of Science Education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and exploration in science laboratories, students who are blind are lack in participating and collecting the information from first hand. 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. In the research system - Listen to complexity system the user is interacting with dynamic objects in a real life scenario.

1. 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. Because most of the science education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and exploration in science laboratories, students who are blind are lacking in participating and collecting the information firsthand. In the last 40 years and longer, manuals were written on how to teach science to students who are blind and visually impaired (Dion, Hoffman, & Matter, 2000; Hadary & Cohen, 1978; Koenig & Holbrook, 2000; Kumar, Ramassamy, & Stefanich, 2001; Willoughby & Duffy, 1989). However, there is little research about how to apply these curricula and their influence on student learning. As a result of the lack of accessibility to educational science material, students are left out or getting the information secondhand (Beck-Winchatz & Riccobono, 2008). As a result of the IDEA97 legislation in 1997, public schools in the United States are required to integrate disabled students within the curriculum. This act has had far-reaching effects for people with disabilities, as it expands their academic skills and knowledge to a wide variety of opportunities. There is a need to support science education research and science teachers with tools and educational materials, which allows the instruction of students who are blind equitable opportunities relative to sighted students. 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.

We propose to give students who are blind equal access to the science classroom, allowing the students who are blind to interact in a research group with science education materials and to collect data independently as participants. Other research (Wies et al., 2001, Farrell, Baldyga, Erlandson, 2001) that has focused on science resources for blind and visually impaired individuals has also recommended using alternative sensory channels such as audio and haptic interfaces. These studies have used audio feedback such as text-to-speech in order to read written material that appears on a website or used a tactile map or a haptic mouse to deliver only a 2D spatial representation.

Auditory assistive technologies include recorded or synthesis voice, earcons, and sonification. However more research and development is need for efficient echolocation feedback. The speech audio includes text-to-speech software and print-to-speech reading machine (e.g., Kurzweil Reading Machine). Over the years several auditory technologies have been developed for people who are blind especially in the field of orientation and mobility, for example, Sonicguide (Warren and Strelow, 1985); Kaspa (Easton and Bentzen, 1999); the vOICe system, which transforms a live image to sound by using a live camera and image-to-sound renderings (Meijer, 1992); talking signs, embedded sensors in the environment (Crandall, Bentzen, Myers, Mitchell, 1995); virtual sound display (Loomis, Golledge & Klatzky, 1998; Loomis, Marston, Golledge, & Klatzky, 2005); activated audio beacon by using cell phone technology (Landau et al., 2005); Miniguide (by GDP Research, 2005); Palmsonar (by Takes Co., 2007); Personal Guidance System (PGS), based on satellite communication (Golledge, Klatzky & Loomis, 1996, Golledge, Marston, Loomis, & Klatzky, 2004); remote infrared audible signage and haptic pointer interface based on PGS (Marston, Loomis, Klatzky, Golledge, Smith, 2006); sound-based VE systems (Sánchez, Noriega & Farías, 2008); and a VE based on audio and haptic feedback for rehabilitation and spatial learning of unknown environments (Lahav & Mioduser, 2004).

A few systems 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 interact with 2D images such as geographic maps, solar system, math and science diagrams, (Landau et al., 2005) and the Line Graphs (Ramloll et al, 2000), which is based on auditory and haptic feedback, to study math. All the technologies above allow the user to interact with a stationary object, and some of these technologies are based on a set-up scenario. Contrary, in the Listen to Complexity (L2C) system the user interacts with dynamic objects in a real life scenario.

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 (Holland, 1995). NetLogo (Wilensky, 1999a) is a programming language for creating agent-based models of complex systems, such as those used in the current study. Exploring such models in chemistry (visual representations) has been shown to be effective in helping students gain a deeper understanding (Ardac & Akaygun, 2004; Kozma, 2000; Levy & Wilensky, 2009b; Snir et al., 2003; van der Meij & de Jong, 2006).

Unfortunately, systems are notoriously difficult to comprehend. Complex systems challenge our understanding, calling for reasoning at different description levels (micro- and macro-), considering interactions among elements, and relating between events taking place at the same time in different parts of the system. Several biases sway people's reasoning about systems: assuming central control even when it does not exist (Resnick & Wilensky, 1993), assigning behavior at one of the system's levels to another (Wilensky & Resnick, 1999), a focus on the system's parts and structure at the expense of attending to its function and mechanisms (Hmelo-Silver & Pfeffer, 2004), and a tendency to view causal relations as a consecutive rather than parallel chain of cause and effects (Chi, 2005). These difficulties point to the importance of educational support in making sense of systems.

Several innovative learning environments have been designed to help people overcome the above-reported biases and understand complex systems, such as constructing and exploring computer models (Ioannidou, Repenning, Lewis, Cherry & Rader, 2003; Klopfer, 2003; Levy & Wilensky, 2009a; Resnick, 1994; Wilensky, 1995, 1997ab, 1999a; Wilensky & Reisman, 2006; Wilensky & Resnick, 1999) and role-playing participatory simulations (Colella, 2000; Klopfer, Yoon & Perry, 2005; Resnick & Wilensky, 1998; Soloway et al., 2001; Wilensky & Stroup, 1999ac, 2000). In this study, we have offered blind people an opportunity to explore computer models through the modality of sound, possibly making such information.

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 differences are found between the 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 people who are blind to mentally model the gas system?

2. 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.

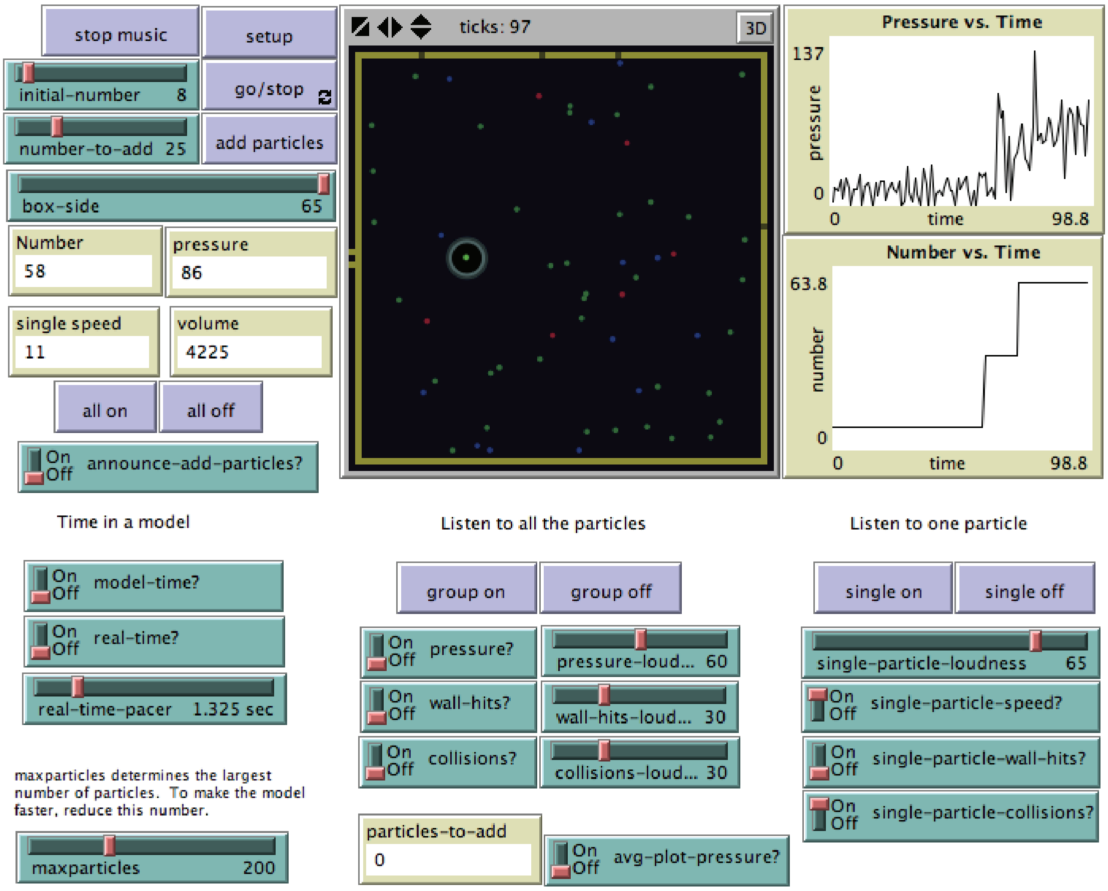

Figure 1. *User Interface.*

3. METHOD

2.1 Participants

The subject, R., is forty-four years old. He has been totally blind since the age of 16 and has been using computers for 25 years. R. learned science in middle school and in college, including about phases of matter and kinetic theory of gases. R. never used computer-based models or simulation.

2.2 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: particles, straight line motion, change in direction results from hitting wall, change in direction results from hitting other particles, change 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, other, more particles lead to greater frequency of collisions, greater density of particles lead to greater frequency of collisions, smaller volume lead to greater density of particles, smaller volume lead to greater frequency of collisions, smaller/greater volume lead to average speed doesn't change, smaller volume lead to distance between collisions decreases, smaller volume lead to more frequent speed changes, more particles lead to more speed changes, and more/less particles lead to same average speed.

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

2.3 Research instruments

The main instruments used in the study were:

NetLogo 4.1 (Wilensky, 1999). The application included a gas lab based on auditory feedback.

Research Protocol. This 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 educational background (during middle school, high school, or later).

Pre- and Post-Test Questionnaire. Identical pre- and post-test questionnaire, this questionnaire included an overview about simulated air particles inside a bicycle tire and ten questions (Levy & Wilensky, 2009b).

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

2.4 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 was the 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; 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, was video-recorded.

4. RESULTS

Research Question One: What differences are found between the 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 in a bike tire representation, particle-particle collisions, extending understanding of pressure to novel situations, and random space-filling distribution of particles. Concepts that were not learned were particles moving randomly with no higher intentions and collisions between particles being 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 describe 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 targets an understanding of 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 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."

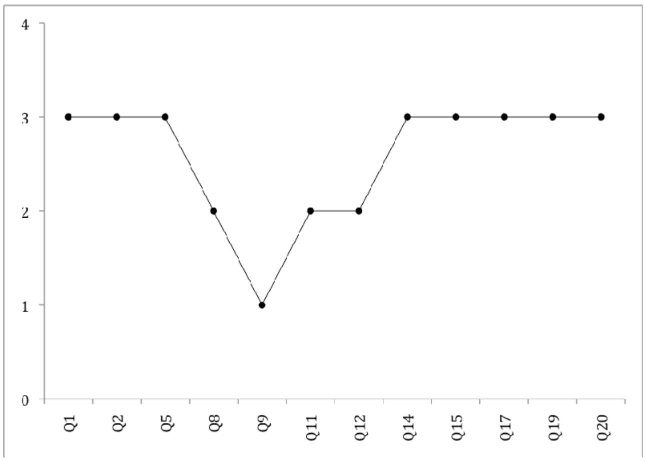

Figure 2. *Progression of subjects' responses to the activity questions in terms of fit to the correct scientific knowledge*

Research question 3: Does the sonified representation of the gas model enable people who are blind to mentally model the gas system?

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." As for integrating two sounds, after listening and connecting collisions and speed changes, he responds positively. In summarizing the activity, R. states "Basically you're learning a new language."

R. suggests several improvements: 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. In addition, he supports 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. At the time of the conference, detailed results from the actual study as well as preliminary conclusions regarding design and learning issues will be presented.

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