Sound-based Computer Models as an Exploratory Learning Environment for Blind Students in Science Education

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Abstract

Although blind students are integrated into public schools, they are often excluded from full participation in science as most learning materials are visual, thus limiting equity. To overcome this limitation, an existing model-based inquiry-learning environment was adapted by means of sonification. We examine whether perceptual compensation creates a comparable learning environment for blind and sighted students. We assess conceptual learning in science and reasoning about complex systems. Data were collected by pre and post questionnaires and answers to workbook items. The environment not only supported blind students' learning similarly, but even furthered their learning with one of the more challenging concepts - diffusion. It seems auditory representation increases sensitivity to the micro-level interactions in a way less accessible in visual representations.

Keywords: special education, technology in educational, science education, computer assisted learning, agent based learning, complex systems learning, dynamic complex systems.

Objectives

How can we support students who are blind in gaining access to exploratory learning materials in science? Listening to Complexity (L2C) addresses a central need among people who are blind: providing equal access to the science classroom, allowing them to interact with exploratory materials, independently collect data, adapt and control their learning process. Its design is based on the assumption that the supply of appropriate information through compensatory sensory channels may contribute to science learning among blind students (Passini & Proulx, 1988).

Blind students have been integrated into public schools for decades. However, since most learning materials in science classes are based on visual information, they are often excluded from full participation (Beck-Winchatz & Riccobono, 2008). Several manuals have been written on how to teach science to students who are blind and visually impaired (Kumar, Ramassamy, & Stefanich, 2001; Willoughby & Duffy, 1989). Few learning environments based on assistive technologies have been created to support science learning and research regarding such technologies is sparse (Farrell et al., 2001, 2008; Wies et al., 2000; Zaborowski, 2006).

In an attempt to overcome this constraint, an existing model-based inquiry-learning environment (Levy & Wilensky, 2009a, 2009b; Samon & Levy, 2013) was adapted for blind students by means of sonification, the use of non-speech audio to convey information (Kramer, 1994). Sonified interfaces can utilize at least five of seven principles of universal design: (1) appropriate use; (2) flexible usability; (3) simple, intuitive use; (4) accessible and easy to remember information; and (5) resistance to mistakes (Connell et al., 1997; McGuire, Scott, & Shaw, 2006). Over the years, several *auditory technologies* were developed for blind people (e.g. BlindAid, Lahav et al., 2008; vOICe, Meijer, 1992).

The L2C models enables users to interact with dynamic objects that are computed in real time, providing a heightened sense of reality while learning about complex scientific phenomena. It is unique with respect to state-of-the-art learning technologies for blind people, in its sonified representation of *dynamic complex* systems, providing access to quickly changing information of both micro- and macro-levels in a system. Important to future dissemination, it is a low-cost technology based on the robust and continually-developing free NetLogo platform (Wilensky, 1999). In the current study, we compare learning outcomes and processes for a set of curricular materials in an auditory mode among blind students and in a visual model among sighted students.

In previous studies (Levy & Lahav, 2012) we had investigated the viability of such an approach with one model and one activity with a small sample of blind adults and found learning gains for some but not all science and systems concepts. Later studies (Lahav, Kittany, Levy, & Furst, 2014) have investigated various properties of sound that would optimally convey the most information in a way convivial for our target audience. In the present study, we examine whether such perceptual compensation creates a comparable learning environment for blind and sighted students. The research expands knowledge about how the auditory channel may compensate and complement for the visual channel among blind individuals for learning complex systems.

Theoretical Perspectives

The L2C environment is aimed at teaching students about Kinetic Molecular Theory (KMT) and Gas Laws, fundamental to the understanding of many advanced concepts in the physical sciences (NGSS, 2013). One of the challenges of gaining a well-developed understanding is that chemical systems can be described in at least three different modes: an invisible molecular submicroscopic level, an experienced macroscopic level and symbolic representations (Johnstone, 1993). Research has shown that students often lack deep understanding of all three modes and often fail to coordinate between them (Novick & Nussbaum, 1981; Nussbaum, 1985).

Complex systems approaches have come into the limelight in several different domains of science and in education and are based on the following idea: a system can be modeled as many entities that operate according to a small set of simple rules, their concurrent actions and interactions emerging into global patterns (Bar-Yam, 1997). This research aligns with the recently published US framework for science education (NGSS, 2013) that underscores system models as one of the central crosscutting concepts. A complex systems approach to teaching chemistry has been shown to help students overcome these obstacles (Holbert & Wilensky, 2014; Levy & Wilensky, 2009a, 2009b). One way of introducing students to dynamic complex systems is by means of agent-based modeling (ABM) in which a computer model simulates the many autonomous, interacting entities of the system.

We assess both conceptual learning in science and reasoning about complex systems among sighted and blind students with guided exploration of an ABM learning environment in which micro- and macro-level variables and events are either visual or sonified. Our research question is: How do conceptual learning, systems reasoning and learning processes with sonified feedback models for blind students compare with such learning through a visual feedback model for sighted pupils?

Method

The L2C Learning Environment

The learning environment consists of eight activities and is four lessons long. It is based on two earlier curricula (Samon & Levy, 2010) and includes guided exploration of agent-based NetLogo (Wilensky, 1999) computer models, laboratory demonstrations and class discussions. They include a microscopic representation of a gas in a container in the form of particles (points) located within a rectangle (representing a vessel). The first models introduce students to the concept of a scientific model and to the use of NetLogo. With each additional model students explore a new function, which allows them to discover a new characteristic of the nature of gases. A workbook for the use of the students accompanies the unit. For most of the unit, students can progress at their own rate with the workbook providing guiding information and guiding questions. Table 1 presents an overview of the unit.

Table 1: Learning Unit Overview; Windows of Learning Progression

Activity	Details	Progression Analysis Windows
Pre-unit questionnaire	Students fill-in the pre-unit questionnaire	
Introduction	Students are shown three phenomena that relate to air pressure. They are asked what the three phenomena have in common and are asked to explain one phenomenon.	T1: 6 items, 5 open, 1 closed
Activity 1 *What is a model?*	The concept of scientific models is discussed. Students are shown a bicycle wheel, which will be modeled in NetLogo in the following activities.	
Activity 2 *The computerized model*	Students learn how to use the computerized NetLogo model and investigate the motion of particles in the model.	T2: 6 items, 3 open, 3 closed
Activity 3 *The Kinetic Molecular Theory*	The main principles of Kinetic Molecular Theory are introduced without a model. This activity summarizes activity 2.	
Activity 4 *Pressure*	By investigation students learn that pressure is caused by particles hitting a surface.	
Activity 5 *What effects pressure*	Students learn the effects of quantity of particles, volume and temperature on pressure. In effect they learn a qualitative version of the gas laws.	T3: 5 items, 1 open, 4 closed
Activity 6 *Diffusion*	Students learn about diffusion as a macroscopic phenomenon that can be explained by microscopic particle behavior.	
Activity 7 *Atmospheric pressure*	Students learn how pressure varies with altitude. This is an advanced activity meant for those students who excelled in the rest of the unit. Only few students reached this activity.	
Activity 8 Summary	Students are asked to refer to the three phenomena presented in the introduction and try to explain them using what they learnt	T4: 3 items, all open
Post-unit Post-test Questionnaire		

The models were adapted for blind students by sonifying events and properties of a single particle such as collisions and speed, as well as global variables such as pressure. This curriculum was available to the participants as text-to-speech file and in Braille. Figures were presented as tactile images.

Participants

The experimental group consisted of ten blind students [missing info on age, gender]. The comparison group consisted of 31 seventh grade sighted students who attend a school serving a high socioeconomic population. Students were distributed approximately evenly between genders. Seven students' data was excluded (completed less that 18/24 questionnaire items, workbook was largely empty).

Research Design

To investigate the comparative learning of blind and sighted students a two-group pre-test-intervention-post-test quasi-experimental design was used.

Data Sources

Data collected included students' responses to pre-post questionnaires and workbook items. The questionnaires included three open items and 22 closed items, and were developed to align with the curriculum. To do so, the items in the workbook were coded for scientific content, systems thinking and reasoning types (declarative, procedural, schematic or strategic, Shavelson, Ruiz-Primo, Li, & Ayala, 2003). Questionnaire items were designed in similar proportions. Most items were validated and used in previous research (Levy & Wilensky, 2009b; Samon & Levy, 2013) and printed in four differently-ordered versions. The workbooks included 229 items, out of which four groups of items were selected as windows for analysing students' ideas as they change (Table 1).

Procedure

Blind students worked and were observed individually. Each session lasted 60 minutes, and the research consisted of ten sessions that were distributed over 5-8 weeks.

Sighted students worked in their school's computer lab, 1-2 students to a computer, during four double-periods over two weeks. Each student had a workbook. The teacher and researchers conducted relatively few conversations, mainly to support students' understanding of the workbook instructions.

Both groups completed identical pre- and post-test questionnaires. Data collection was conducted differently for the two groups. While blind students worked individually with a researcher, sighted students worked individually or in pairs within a classroom setting. The choice results from the study's main goal to compare the blind students' learning with learning in normal school settings, and the scarcity of blind individuals.

Analysis schemes

Overall learning gains: An overall score for each pre- and post-questionnaire was calculated by awarding 1 point for each correct answer. From this data overall scores for each student were calculated. The aggregated scores for sighted and blind students were compared.

Learning of specific scientific concepts and systems reasoning: Questionnaire items were grouped according to the scientific concepts and central systems ideas. Scores were computed for individual students and were then aggregated and compared.

Learning process: In-depth analysis of four groups of items or 'windows' in the workbook provided information about the learning process (Table 1). Answers were analyzed according to a coding scheme for both scientific content as well as systems reasoning (Table 2).

Table 2. Coding scheme for the workbook items included in the windows

Scientific content
Gases is compose of particles
There are different types of particles
Particles move in straight lines
Particles collide with one another
Particles collide with the walls of the vessel containing the gas
Particles change direction upon collision with a wall
Particles do not change their speed upon collision with a wall
Particles change their speed upon collision with a wall (incorrect)
Particle change direction upon collision with one another
Particle change speed upon collision with one another
Particles move in random directions
Particles scatter around the room
Particles have no free will
Particles have a free will
Pressure is caused by particles colliding with the walls of the vessel
Reference to pressure in the macro level
Reference to volume in the macro level
Reference to density
Pressure is effected by the number of particles in the vessel (micro)
Pressure is effected by the quantity of gas in the vessel (macro)
Volume is effected by the quantity of gas in the vessel (macro)
Pressure is effected by changes in the volume of the vessel (macro)
Pressure is effected by changes in the volume of the vessel (micro with reference to particles)
Pressure changes with the temperature in the vessel
Diffusion as a macro phenomenon (gas moves from high to low concentrations)
Diffusion as a micro phenomenon (particles move freely and at random)
Ideas in systems thinking
Reference to the micro level
Reference to the macro level
Interaction between agents at the micro level
Emergence – Interactions at the micro-level cause the system to rearrange thus effecting macro behavior
Slippage between levels – use of language suitable for the micro level to describe the macro level (and vice versa)
Reference to centralized control
Reference to decentralized control
Uncertainty
Dynamic equilibrium

Validity

The construct and criterion validity of the content knowledge questionnaires was reviewed by five science teachers and two science education experts. All confirmed that the test items were appropriate for examining the issues studied in the two learning environments. Coding were checked by the researchers and an external expert in science education. Agreement was high and disagreements were resolved uniformly by discussion.

Findings

Overall Learning Gains

Group scores rose significantly from pre- to post-tests (Table 3). Blind students started out with a similar score to that of the sighted students, but their post-test score is significantly higher (Mann-Whitney U=36.0, p<.01). Learning gains are comparable, though insignificantly higher for the blind students.

Table 3. Pre-test and Post-test Scores (%) and Learning Gain Comparisons for the Blind and Sighted Students, Overall, by Concept

	Blind Students		**Sighted Students**		**Learning Gain Comparison**
Learning Concepts (# of items)	***Pre-test M (SD)***	***Post-test M (SD)***	***Pre-test M (SD)***	***Post-test M (SD)***	***Mann-Whitney U***
Overall (22)	58 (12)	83 (10)	53 (17)	64 (18)	90.0
Science concepts					
KMT (10)	48 (19)	78 (14)	50 (21)	60 (21)	177*
Diffusion (4)	45 (20)	80 (16)	53 (32)	47 (39)	145**
Density (3)	47 (28)	77 (16)	56 (35)	72 (25)	138
Gas laws (9)	68 (13)	85 (7)	55 (19)	72 (20)	112
Systems thinking					
Micro-level (7)	49 (22)	87 (16)	43 (22)	58 (24)	158
Macro-level (7)	70 (8)	93 (14)	57 (21)	64 (21)	160
Emergence (8)	56 (17)	70 (9)	57 (21)	70 (20)	107

Learning of Scientific Topics and of Systems Thinking Approach

With respect to conceptual learning in science, the sighted students mainly learned the Gas Laws, KMT and density to a certain degree and regressed with respect to understanding diffusion. Blind students' learning gains were higher than those of sighted students. Quite distinct from the sighted students, their largest learning gain relates to diffusion. Distinct from the sighted students the Gas Laws showed least improvement, this, however, may be a ceiling effect, as the score in the post-test is 85%. Regarding systems reasoning, the groups are similar in the pre-test and in the post-test.

Learning Processes

Processes of learning along the four windows for both groups are presented in Figure 1 and Figure 2. Comparing these temporal curves shows that for most concepts, the shapes of the curves are similar for the two groups. This is not true for including interactions, uncertainty and decentralized control, where the blind students provided more such explanations earlier in the learning process. Another result from the comparison is the higher proportion of students expressing each of the concepts (systems, science) among the blind group with respect to the sighted group.

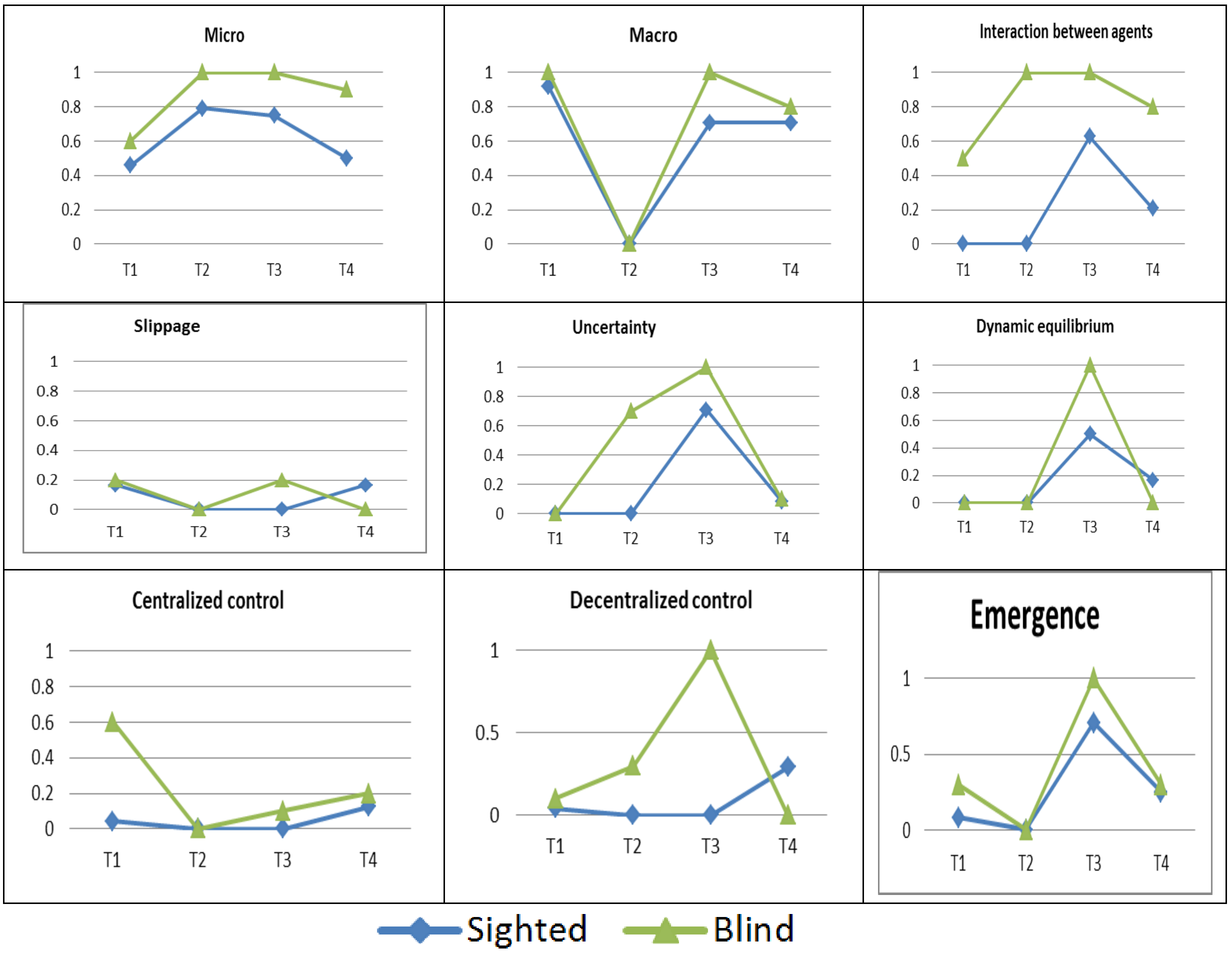

Figure 1. The learning progression of systems thinking components in four windows in the workbook.

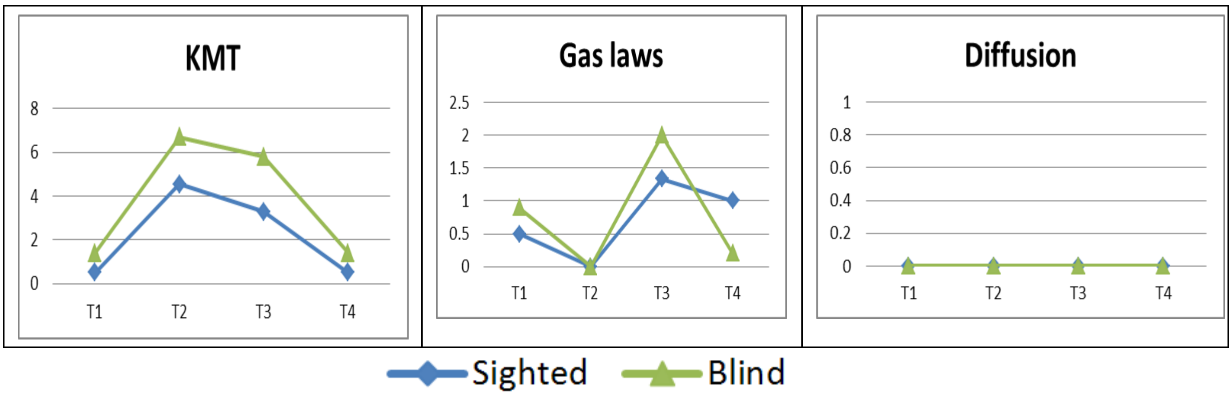

Figure 2. The learning progression of scientific concepts in systems in four windows in the workbook.

Discussion & Significance

The study compared blind students' use of auditory computer models to sighted students use of visual models. With respect to sighted students, the auditory representation not only supported blind students' learning similarly, but was even related to greater learning of diffusion, a challenging concept. In analyzing the progressions we can see that the individual science and systems concepts were learned at similar times, corresponding to the learning materials. However, regarding two central systems concepts: interactions between individuals and uncertainty, the blind students learned and applied these concepts earlier. The L2C's auditory representation seems to have increased sensitivity to micro-level interactions (colliding) in a way that is less accessible in visual representations. We had chosen to sonify particular events for one particle and time progressions of global variables such as pressure. In fact, much information in the visual array is missing in the auditory array: many other particles, each moving about, colliding and bouncing off walls. It would seem that this filtering of information helps students focus on these very interactions that are subtle in an array of many particles, and notice their random changes over time, evidence from which uncertainty can be derived.

Limitations to this study include the different character and treatments of the two groups: the experimental group included young adults, who interacted one-on-one with a researcher, while the comparison group included middle-school students who worked in pairs within a classroom. Such limitations were inevitable due to a limited sized blind population.

Given the success of this low-cost learning environment, extending this design to learning of other STEM systems by using sonified models opens the way to equitable participation of blind people.

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