Computer model based audio and its influence on blind students' learning about gas particle behavior

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ABSTRACT

This paper focuses on the need of students who are blind to access science curriculum learning materials. Net Logo is a widely used computational agent-based modelling language that enables exploring and constructing models of complex systems. The Listen-to-Complexity environment is based on Net Logo and involves sonified feedback that was adapted to users who are blind. This study examines the scientific conceptual knowledge, systems reasoning, and Kinetic Molecular Theory of gas in chemistry that were learned as a result of interaction with the Listen-to-Complexity environment by people who are blind as shown in their answers to a pre- and post-test. Five participants who are blind volunteered to participate in this research. The preliminary findings are encouraging with regard to the sonified model's efficacy in providing access to central and difficult scientific concepts, even when the target phenomenon is complex. The benefits of this longitudinal research are likely to have an impact on science education for students who are blind, supporting their inclusion in the K-12 academic curriculum on an equal basis with sighted users.

1. INTRODUCTION

Students who are blind have been integrated into public schools and are required to complete the same curriculum and examinations as their sighted peers. However, they are blocked from access to firsthand information because many education-learning resources, especially in the science fields, are based on the visual mode, which employs diagrams, charts, models, and exploration in science laboratories (Beck-Winchatz and Riccobono, 2008). In their learning process, people who are blind gather information through perceptual and conceptual tools (Passini and Proulx, 1988). At the perceptual level, haptic, auditory, and olfactory senses compensate for the shortage of visual information. Technology learning systems developed to support Science, Technology, Engineering, and Mathematics (STEM) education among students who are blind are scarce. They include the Talking Tactile Tablets (Landau, Russell, Erin, and Gourgey, 2003), which are based on audio and 2D tactile materials and support interaction with 2D images for learning mathematical and science diagrams. The Line Graphs technology is based on auditory and haptic feedback and is geared to learning mathematics (Ramloll, Brewster, and Burton, 2000).

Agent-based modeling is a computational modeling paradigm that simulates complex dynamic systems by simulating each of their many autonomous and interacting elements. The NetLogo (Wilensky, 1999; Levy and Wilensky, 2004) modelling platform is based on previous research into learning about complex systems using models with sighted students (Levy and Wilensky, 2009a, 2009b). The current paper delves into issues of auditory perception that accesses such dynamic information through multiple parallel representations. The Listening to Complexity (L2C) system is based on the principle of perceptual compensation using technologies (Lahav and Levy, 2010; Levy and Lahav, 2011). L2C harnesses the auditory mode to transmit dynamic complex information. The choice of an auditory display results from three considerations: (a) the auditory mode transmits information that changes both in space and time, like the visual mode and unlike the haptic mode; (b) the auditory mode easily interfaces with large bandwidths at fine frequency-discrimination and intensity-discrimination thresholds (Capelle Trullemans, Arno, and Veraart, 1998); (c) the auditory system is used to deal with complex and rapidly changing sound patterns (Hirsh, 1988). Research into the impact of different components of sound on auditory perception has shown that increasing the number of channels beyond three causes degradation in comprehension (Stifelman, 1994) and that a greater frequency separation between sound streams results in better stream segregation (Bregman, 1990).

In the current research, we use sound to represent a dynamic rather than a static array. The referents of the dynamic representation are multiple and operate at two system levels. Going beyond established research, we explore how a combination of several factors may impact auditory perception of sound. This study continues to explore auditory compensation for visual information among students who are blind and also looks at perception of dynamic and complex displays and learning about dynamic complex systems.

The learning system that is used in this research is based on transmittal of visual information of dynamic and complex systems, providing perceptual compensation by harnessing auditory feedback. The feedback consists of sonification of variables: wall hits (represented by the sound of a bat hitting a baseball), particle collisions (represented in the L2C system by the sound of two billiard balls colliding), announcement of particle addition, and events that are registered as sounds on an audiograph: velocity (telephone-dash speed), temperature, pressure, and volume. The agent-based NetLogo computer model of gas in a container is used to convey information regarding both individual gas particles, such as particle collisions, a particle hitting the wall of the container, and system wide phenomena, for example, pressure, using alerts, object and status indicators, data representation, and spatial audio displays (Figure 1). In the figure, the square on the right represents a container and the dots inside represent the gas particles. The particle surrounded by a circle represents the observed particles. This research improved the understanding of the processes through which perception of sound takes place and transforms into conceptual change through interactions with dynamic complex systems. It also examined the ability to access science information through a sonified learning system and its effect on learning and the understanding of complex systems among people who are blind.

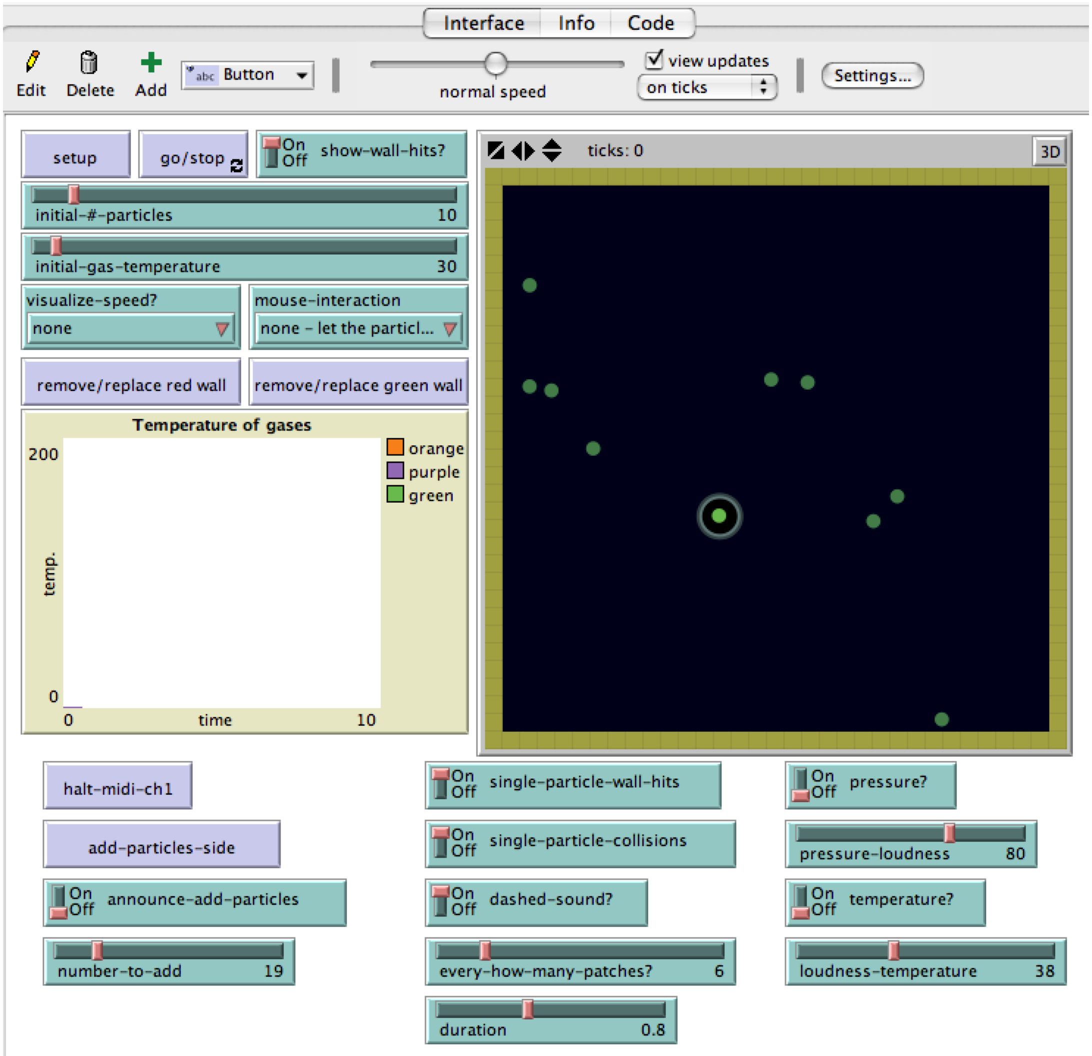

Figure 1. *L2C sonified model of gas particles in a container. Bottom-right are variables and events that relate to a single focal particle. Bottom-middle are variables and events that relate to the group of particles.*

2. METHOD

2.1 Participants

This research studied five participants who are blind who worked with the sonified curriculum and were observed individually. They all have the ability to use computers for daily use.

2.2 Instrumentation

The research included one implementation tool and three data collection tools, described below:

L2C learning materials with sonified model. The learning materials are based mainly on Chapter 1 of the Connected Chemistry curriculum (CC1) (Wilensky, 1999). The L2C sonified model is based mainly on this chapter, which involved 62 open-ended questions and 144 multiple-choice questions. This chapter included seven activities: what is a model?, the computerized model, kinetic molecular theory, pressure, changing pressure, diffusion;, and atmospheric pressure and gravitational force. The original curriculum was developed based on CC1 by Samon, Peleg, and Levy (2014). This curriculum has been rewritten adaptively to the target population by the researcher, using the universal design learning methodology (CAST, 2011). For example, some images were described in words and others were tactile printed. This curriculum was available to the participants as text-to-speech file and in Braille, and in both representations the images were presented as tactile images. All images were printed in a Swell-Form Graphics Machine (a fuser) manufactured by Zychem using a standard print on Swell-Touch paper and running this paper through the Swell-Form Graphics Machine. The heat from the machine reacts with the black ink and causes it to "swell", creating the tactile image. Participants were able to read or listen to the files and to explore the tactile images that were embedded in the text. In addition, instructions on how to run the computer model and which variables to activate preceded each computer task. It would be preferable if the participant were able to operate the computer model independently. Unfortunately, in this version the participant was unable to do so and needed the researcher to operate the computer model for the participant. We hope that next version will allow the user to activate the L2C independently.

Background questionnaire. This questionnaire included personal information, science education, and computer technology use.

Pre- and post-test questionnaires. The pre- and post-test questionnaires included assessment of the learners' understanding of the gas laws and kinetic molecular theory, were identical, and contained both open-ended questions (three questions) and multiple-choice questions (22 questions). Most items were a subset of those that have been previously developed (Levy and Wilensky, 2009b). The pre- and post-test questionnaires were rewritten for the target population using the universal design learning methodology (CAST, 2011).

Research protocol. A research protocol was developed and contained the research activities from the ten sessions: introduction; pretest questionnaire; learning intervention using the L2C learning materials with sonified model; and post-test questionnaire.

2.3 Data Analysis

Quantitative analysis was based on previously developed coding schemes. The participants' answers to the pre- and post-test questionnaires and to the L2C learning materials with sonified model questions were transcribed and coded for conceptual understanding and reasoning in terms of complex systems. The data analyses were consistent with previously developed coding schemes (Lahav and Levy, 2010). Data analyses were based on participants' verbal answers to the questions presented in the questionnaires and activities. These answers were coded for the dependent variables: scientific conceptual knowledge and systems reasoning. With respect to scientific conceptual knowledge, questions were coded based on previous coding of the same questions (Levy and Wilensky, 2009b; Samon and Levy, 2013). Multiple-choice questions were coded as correct or incorrect, and open questions were coded for the relevant correct scientific principles they included. For systems reasoning, the open questions were coded based on three central components (Wilensky and Resnick, 1999; Jacobson, 2001) that described the structure of the explanation. For the pre- and post-test, descriptive statistics were compared, and progressions of frequencies were computed and related to the activity. The quantitative analysis used statistical software such as Excel and SPSS, according to participants' answers to the pre- and post-test.

2.4 Procedure

All participants worked and were observed individually. Each session lasted 60 minutes, and the research consisted of 10 sessions that were distributed over 5-8 weeks. Identical pre- and post-test questionnaires were used to assess learning and answers throughout the activity. No feedback was provided on performance at any stage.

3. RESULTS

It was found that participants' score for the pre- and post-test questionnaires rose from 54.2% to 76.7%, a statistically significant difference. A more discriminate analysis shows that in the multiple-choice questions, participants' score for the pretest and post-test questionnaires rose from 50% to 70%. The open-ended questions included three topics: diffusion, atmospheric pressure and gravitational force, and changing pressure (Table 1).

Table 1. *Comparison of participant knowledge in the pre- and post-test.*

	Open-ended questions 15%			Multiple-choice questions 85%	Mark 100%
	Diffusion	Atmospheric pressure and gravitational force	Changing pressure		
Pre-test	2.1%	1%	1.1%	50%	*54.2%
Post-test	2.7%	2.3%	1.7%	70%	*76.7%

*p<0.01

On an overall average for the open-ended questions, participants' score rose from 26% in the pretest to 46% in the post-test (Figure 2).

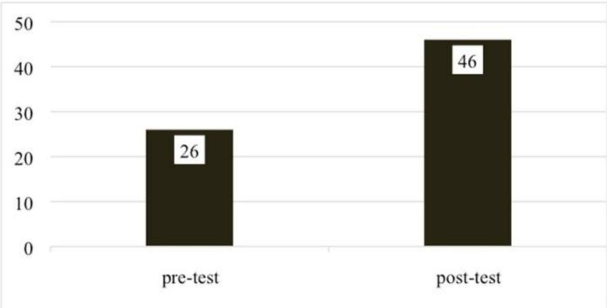

Figure 2. *The open-ended questions in the pre- and post-test.*

Test questions were divided according to three levels of difficulty (1 easy, 2 medium, 3 difficult), and the first-level test score rose overall from 60% in the pre-test to 86% in the post-test. The intermediate level score increased from 52% to 91%, and the difficulty level increased from 50% to 85%, as shown in Table 2.

Table 2. *Participants average in pre- and post-test by difficulty in percent.*

Difficulty	Pretest	Post-test
Level 1	60	86
Level 2	52	91
Level 3	50	85

In further analysis of the answers to test questions, across the seven educational activities of the unit, participants were found to have a significant increase in grade for all subjects in each of the activities. Figure 3 presents the pre- and post-test grade details in the seven activities.

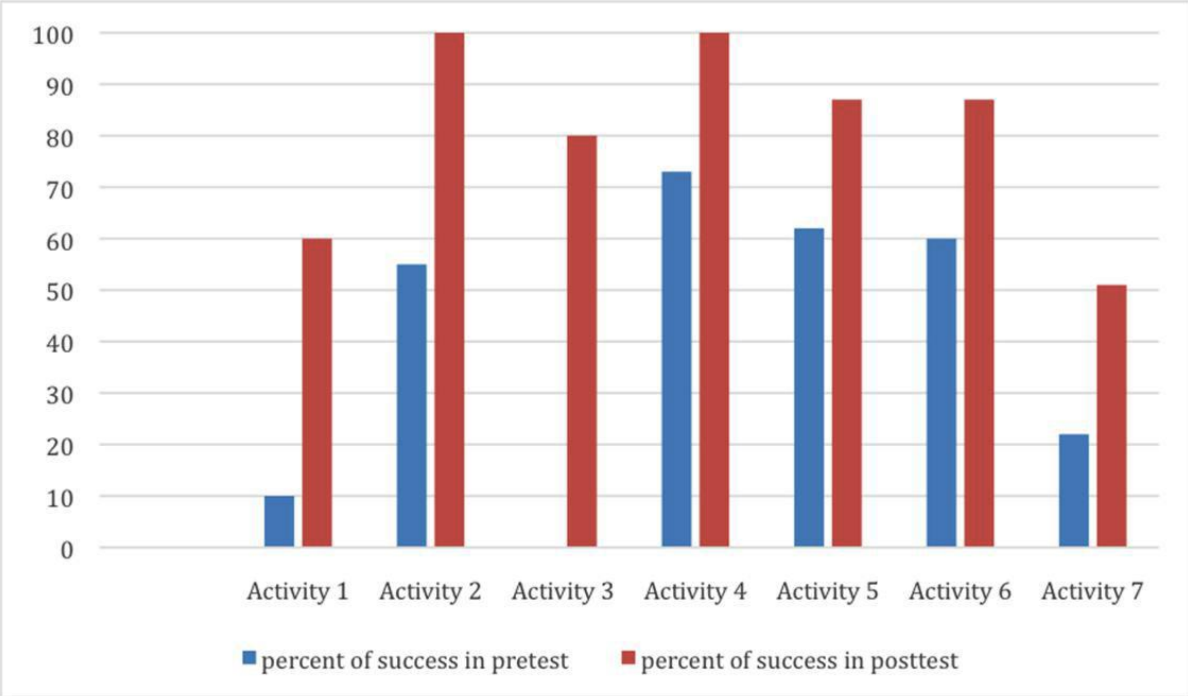

Figure 3. *Participants average in pre- and post-test by activities.*

4. CONCLUSIONS

The preliminary findings are encouraging with regard to the sonified model's efficacy in providing access to central and difficult scientific concepts, even when the target phenomenon is complex. The study results express the high-level ability of the participants to learn STEM material with a complex dynamic model using sonification feedback.

Besides the cognitive learning performances, all learning activities were based on complex sonified information and included four to five types of different sonification feedback that were played at the same time, for example, during the activities: pressure macroscopic and microscopic concepts, changing pressure, diffusion, and atmospheric pressure and gravitational force. In these activities the participants were required to listen simultaneously, using the model, to particles colliding with each other, particles colliding with the wall, adding particles, pressure, temperature, and speed. By means of this special auditory and cognitive capability of the software, the participants succeeded in the learning activities and improved their knowledge in the post-test questionnaire.

The type of question had minor effect on the participants' success. There was only a small difference in the participants' answers to the open-ended questions compared to the multiple-choice questions. The type of learning activities questions on the pretest questionnaire had almost the same percentage of success, but higher differences were found in the post-test questionnaire. For all seven activities, higher grades were found in the post-test questionnaire at all three levels of difficulty.

The results of this study have important implications for the continuation of the research and also for its implementation. Additional research is needed to compare the effectiveness of an accessible learning curricular textbook integrated with a sonified NetLogo model learning environment versus an accessible learning curricular textbook alone. This research should explore the benefits of learning with L2C relative to learning through standard learning materials among students who are blind.

The long-term practical benefits of this research are likely to have an impact on STEM education for students who are blind, as equal access to low-cost learning environments that are equivalent to those used by sighted users would support their inclusion in the K-12 academic curriculum.

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