An Investigation of Sonification as an Instructional Variable to Improve Understanding of Complex Environments

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Abstract

Sonification, the use of nonspeech audio to convey information, was used to test whether the simultaneous presention of visual and artificially created auditory (sound) information significantly improves scores on comprehension tests of complex, dynamic computer simulations of an ecology microworld over scores from college participants who were presented visual information alone. Brief training was provided and all tasks were completed online. Participants were also tested for musical aptitude and preferred learning modality. Results indicate that while age and grade point average significantly predicted score on the comprehension test, the treatment did not. For one-month retention of knowledge, only grade point average was significant. Nevertheless, positive effect sizes and opportunities for improvement in the presentation of information invite a follow-up study.

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Chapter One: Introduction

Today's world is more crowded and interconnected than ever. Rapidly advancing technology allows for dramatic increases in human interaction and our generation is witnessing a time of general prosperity in quality and longevity of life. Along with continued intercultural and intracultural struggles, however, our rising numbers are putting ever-increasing pressure on our planet's resources. More than ever, what we do affects our environment and those around us, and so we have an urgent social and psychological need to understand our behavior and its consequences.

With greater population density comes greater interaction, especially in the face of rapidly advancing technology. Increasing human activity also drives the increasing supply of and demand for information and the mountain of information available to us is growing faster than our collective ability to scale it. Put another way, we face an ever-increasing challenge to understand and manage a world of complexity. In education, an increasing number of students need to become proficient in analyzing data (Healy, 1998). Educational psychology must guide us in our search for new tools and approaches in trying to meet this challenge.

While we are no doubt more interconnected and more "informed"—more information is readily accessible—however, we are not necessarily selecting, filtering, processing and recalling information any better. Technology such as the Internet creates a challenge for educational psychologists to create learning environments that facilitate the management of our ever-expanding body of available information. We must therefore periodically examine our traditional methods of analysis and pedagogy in promoting data literacy. How can technology be more fully utilized to manage the burgeoning amount of information and the application of that information in productive ways? What alternatives to traditional approaches such as visual representation of data might offer new benefits to learning and insight to understanding? Are there any combinations of tools and methods that might prove particularly useful in improving our understanding of basic components to complexity?

The proficiencies in data literacy that we currently attempt to develop in students are centered on creating and interpreting visual representations of the data. Beyond the problems encountered by those with sensory impairment, however, this educational approach remains somewhat ineffective, as many people struggle to understand the information embedded in the data. As a veteran educator explains,

> You can interpret pictures, charts, and graphs any way, and kids tend to be very strong believers in both visuals and data. Yet most of the data collected about Earth is very noisy—it has lots of errors because there are so many complex interactions. In fact, most real-life data is fraught with problems, and it's very easy to lie with statistics. Even most adults don't really know how to understand visual diagrams like graphs, so it's easy to misrepresent findings (Healy, 1998, p. 303).

Perhaps we have always shown a bias toward visual learning; in terms of evolutionary development, hearing came after vision, touch, taste and smell (Jourdain, 1997). Evolution may also explain why we also have hearing differences in directional ability. Jourdain reports that we can differentiate side-to-side sounds—lower-pitched sounds, under 1,000 Hz, better than higher-pitched ones—as close as one or two degrees apart, but at best about four degrees apart for sounds from above (Jourdain, 1997). Our reliance on speech communication may also explain these differences; nevertheless, visual cues from facial expressions and body language remain a dominant influence in human communication, for the hearing impaired and unimpaired alike.

That visuals seem more helpful to some than others, however, gives rise to the notion of preference learning, i.e., that some of us describe ourselves as primarily visual learners—we are capable of learning information presented in various forms but seem to prefer learning when the information is presented visually—while others may be auditory or kinesthetic learners. Because visual learners comprise a considerable portion of the population (Sousa, 2001), it would seem evident that visual representations of data such as graphs and pictures are the most appropriate method of conveying information.

However, visuals may sometimes hinder our learning process; some students may like pictures but learn little from them. Even those who have a visual learning preference may encounter problems with learning information presented in words and pictures simultaneously. The difficulty in combining words and pictures to most effectively support instructional goals while keeping the message clear and engaging is an on-going challenge, particularly in document design (Schriver, 1997). How, then, can we do better?

Perhaps the answer lies not in presenting information in different forms that appeal to the same (visual) learning style but rather in converting that information to different forms that can be presented simultaneously to accommodate different learning styles. One example lauded by mathematics educators is a set of Cuisenaire rods, which appeal to children's kinesthetic sense as well as to their visual sense (Holt, 1982). By appealing to both senses simultaneously, Cuisenaire rods have proven extremely effective in helping to build children's facility in numeracy. Perhaps, then, there is also a way—especially with the aid of today's technology—to simultaneously present information visually and auditorially to enrich the learning environment.

Two tools that when combined with today's technology offer synergistic benefits to learning environments for complexity are *system dynamics* and *sonification*, "the use of nonspeech audio to convey information" (Kramer et al., 1997, p. 1). While the origins of system dynamics date back only to the mid-20th century, the study of sound, information and perception are much older. In the 19th century, Helmholtz demonstrated the relationship between physical properties of sound waves and their perceived qualities, such as how adding harmonics—sounds at higher pitches that vibrate at integer multiples of the fundamental tone—affects color or brightness (Dodge, 1997). Today technology can be used in dramatic ways to aid in the study of sound, complexity and perception. In addition, technology offers benefits from using a combination of senses to optimize information processing and demonstrate the many (underemphasized) links between categories of study. As an example, the prototype discussed illustrates not the polish of a finished product but some of the many ways and potential benefits of combining sonification with simulation and educational psychology. Members of the International Community for Auditory Display, or ICAD, write (Kramer et al., 1997):

> Audio's natural integrative properties are increasingly being proven suitable for presenting high-dimensional data without creating information overload for users. Furthermore, environments in which large numbers of changing variables and/or temporally complex information must be monitored simultaneously are well suited for auditory displays.... Through the use of complex nonspeech audio and sophisticated multimodal displays, sonification has the potential to advance basic research in cognition and perception in important ways (pp. 2 and 3.1.3).

While an audio-enhanced environment may offer special benefits to learners with impaired senses, a natural question—for learners with *unimpaired* senses—is whether our senses can somehow be used together to improve understanding of a complex environment. Another question is whether learners with an aptitude in music may particularly benefit from sonification. Further, can sonification be shown as effective to learners, or a group of learners such as ones who express a preference for learning in an auditory modality, without extensive training? Answering these three questions is the thesis of this research: to investigate whether understanding of a computer simulation of a complex, dynamic ecology microworld can be improved by using sonification—where the simulation data is converted to sound (the independent variable)—to allow sensory-unimpaired learners to listen to the information while simultaneously studying the same information presented visually. Embedded in this thesis are methodological issues involving the mapping of variables of interest to sounds that can be quickly and effectively interpreted while accurately conveying information contained in the data.

Hypotheses

The central hypothesis to be tested for this research[1] concerns the potential impact on measurable learning of a learning environment enhanced by adding sound to visuals: Given brief training in sonification, college students from either the University of Minnesota or DePauw University who have taken or are currently taking a class in either ecology or music theory, and who study a computer simulation of a "complex" ecology microworld that presents generated data both visually and auditorially (sound condition), will score higher on an evaluative test immediately following the study than students for whom data are presented only visually (no sound condition).

The use of the term "complex" here refers to an environment that includes interactions of variables under study, or what the field of system dynamics refers to as "feedback loops" in a system. Included in the analysis will be data to help determine whether musical aptitude and/or level of motivation are related to a potential learning effect in an environment enhanced by sonification.

Worth emphasizing is that in the overall methodology of this research the treatment group was given auditory *and* visual information, versus visual-only information given to the control group. This is in contrast to the possibility of having given the sound treatment group *only* auditory information, a situation likely to highlight a training effect and magnify any presentation effect. To this end, the sonification process was automated so as to present the *same* information as that presented visually, thus removing the possibility of a presentation effect.

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1 The experiment can be found on the website www.sonificationexperiment.com.

While the test is to be administered immediately following participants' study of the simulation, retention of information is also of interest. A related hypothesis, therefore, is that participants for whom data are presented both visually and auditorially will score higher on an evaluative test a month[2] or more after studying the simulation than participants for whom data are presented only visually. Further, in addition to testing for an effect—both short-term and long-term—among the entire participant pool in the experiment, this research is designed to test for an effect among subgroups of potential interest, including:

- participants identified as having a high or mild preference for learning in an auditory modality (versus not having an auditory learning preference)
- participants who have not taken an ecology class or have not had experience with simulation models

Additional hypotheses examine the same issue in the long term, as well as for subsets of participants (e.g., ones who demonstrate a high musical aptitude) in both the short and long term. Researchers and practitioners who utilize sonification do not follow a common line of reasoning because, to date, the field has not developed a universally accepted methodology. Therefore, for this research, many factors relevant or potentially relevant to whether learners would benefit from sonification in this particular application had to be considered. Other hypotheses of interest include:

- whether motivation—as measured by grade point average, training-and-test time

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2 In testing for retention of information, the choice of a one-month time interval was an attempt to balance the need for a valid measure of long-term recall with a pragmatic delay interval for retesting that would not yield significant decline in participation.

and retention time, level of enjoyment and level of interest—contributes to an improvement in auditory-plus-visual performance over that of visual-only scores for any of the responses (total score, one of the sub-scores, or any of the retention scores or decay scores)

- whether any of the independent variables—age, class, university, major, ecology class (yes/no), general simulation experience or familiarity with the featured simulation, handedness, experience with a musical instrument, listening environment, learning preference, musical aptitude, or training effectiveness—account for any effect in either total score, one of the sub-scores, or any of the retention scores or decay scores

- whether any of the independent variables—experience with a musical instrument, major, university or auditory-preference learning—are correlated with any of the chosen measures for musical aptitude (tonal, rhythm or overall)

- whether number of tries to correctly answer the training item is correlated with whether participants found the training adequate or helpful

- whether time (days) between post-view and retention measurements is related to decay scores either for all items or for author items

Training time is relevant to each of the above hypotheses. The current study is constrained by limited resources that are provided only a minimum of training, which in turn may impact results since the method may be new to all participants in the experiment. Yet this study may also contribute to a methodology. The prototype showed that by using additive synthesis, a number of parameters could be represented with a single sound by utilizing the various components of sound and how we interpret it: pitch, timbre, rhythm, reverberation, spatial panning. The prototype also revealed, however, that decisions about how to map parameters of interest onto sonic components are largely a matter of choosing what is to be emphasized in the learning environment. In addition, feedback from users and observers suggested that there would be considerable variability in how quickly and how completely users would understand sonified data. Such variability alludes to the training challenge presented by combining a new auditory method of learning with visual methods that learners have known and understood much of their lives.

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